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(54) **PROJECTOR COMPRISING AN OPTICAL COMPONENT HAVING A ROCK CRYSTAL MEMBER**

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(52) **U.S. Cl.** **353/20**; 353/122; 359/500; 349/9

(58) **Field of Search** 353/20, 31, 33, 353/34, 37, 81, 82, 122; 359/500, 487; 349/5, 6, 7, 8, 9

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(57) **ABSTRACT**

The projector comprises: an illumination optical system for emitting light; an electro-optical device for modulating the light emitted from the illumination optical system in response to image information; a projection optical system for projecting a modulated light generated by the electro-optical device; and an optical component having a rock crystal member composed of rock crystal, the optical component being located in an optical path including the illumination optical system and the projection optical system. For example, the optical component provided on a light incident side or a light exiting side of the electro-optical device has a rock crystal substrate **308**G as the rock crystal member and a polarizing plate **302**Go arranged on the substrate. It is preferable that a Z axis of the rock crystal substrate **308**G is set to be substantially parallel to or substantially perpendicular to the surface of the substrate.

5 Claims, 11 Drawing Sheets

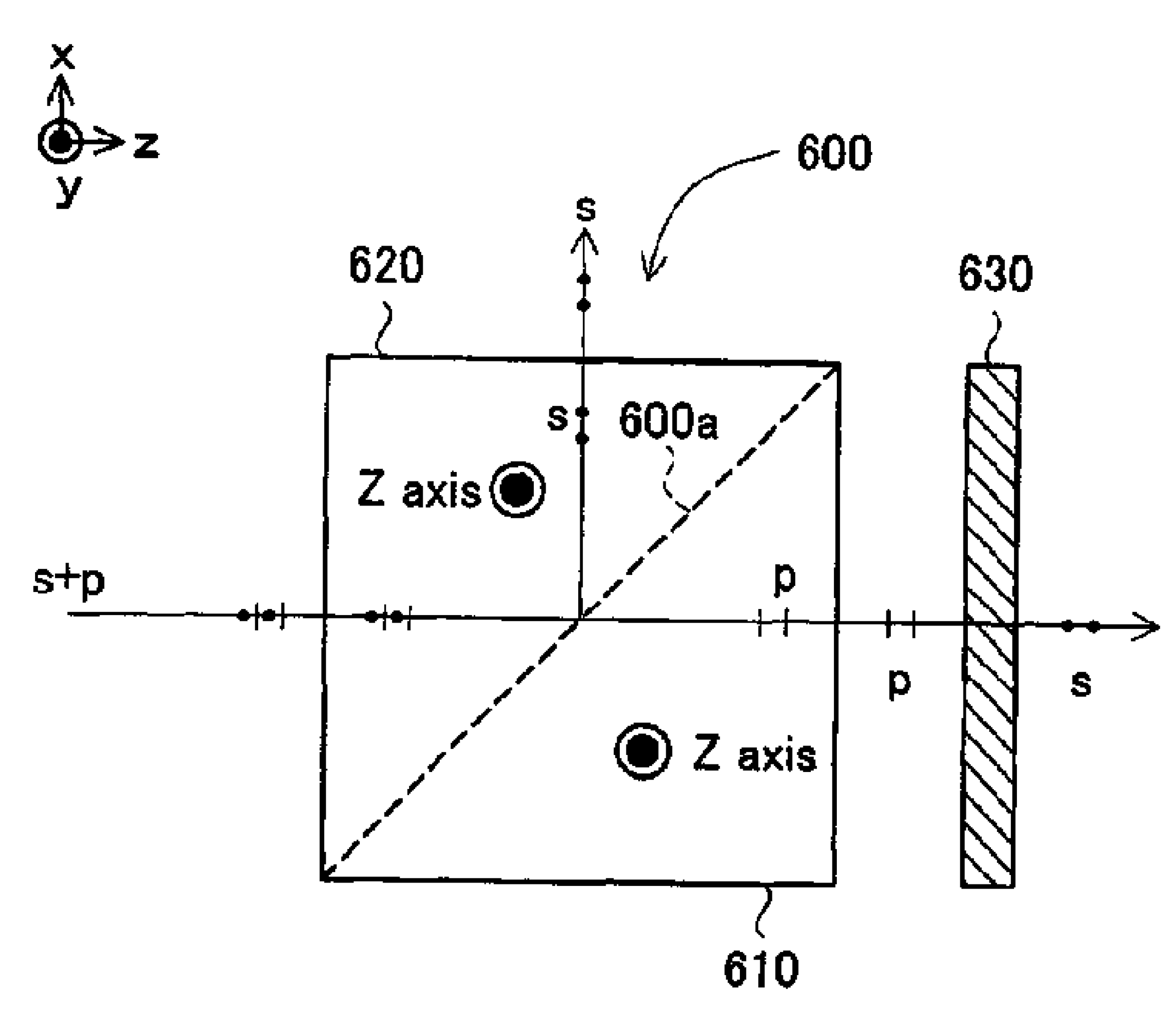
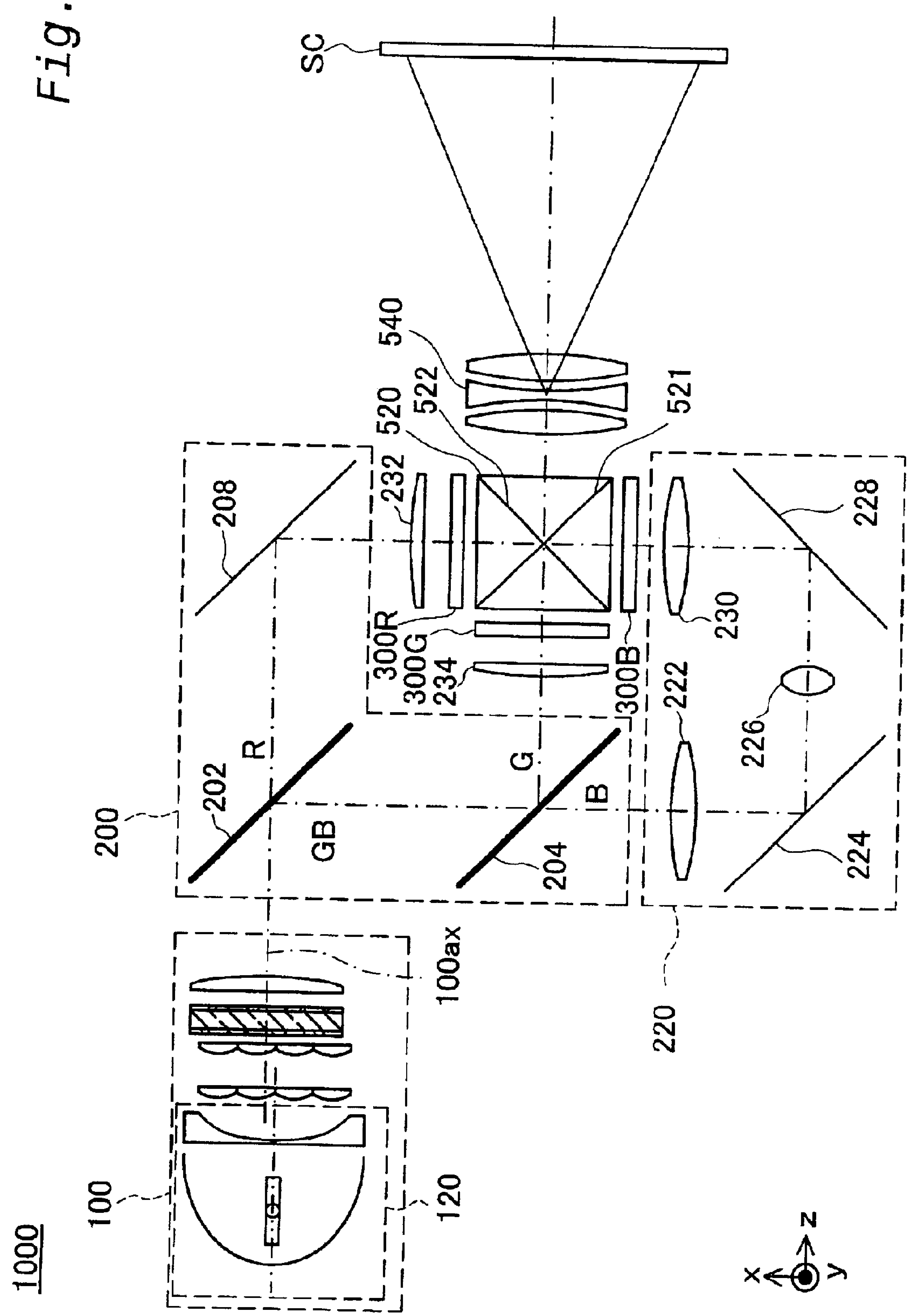
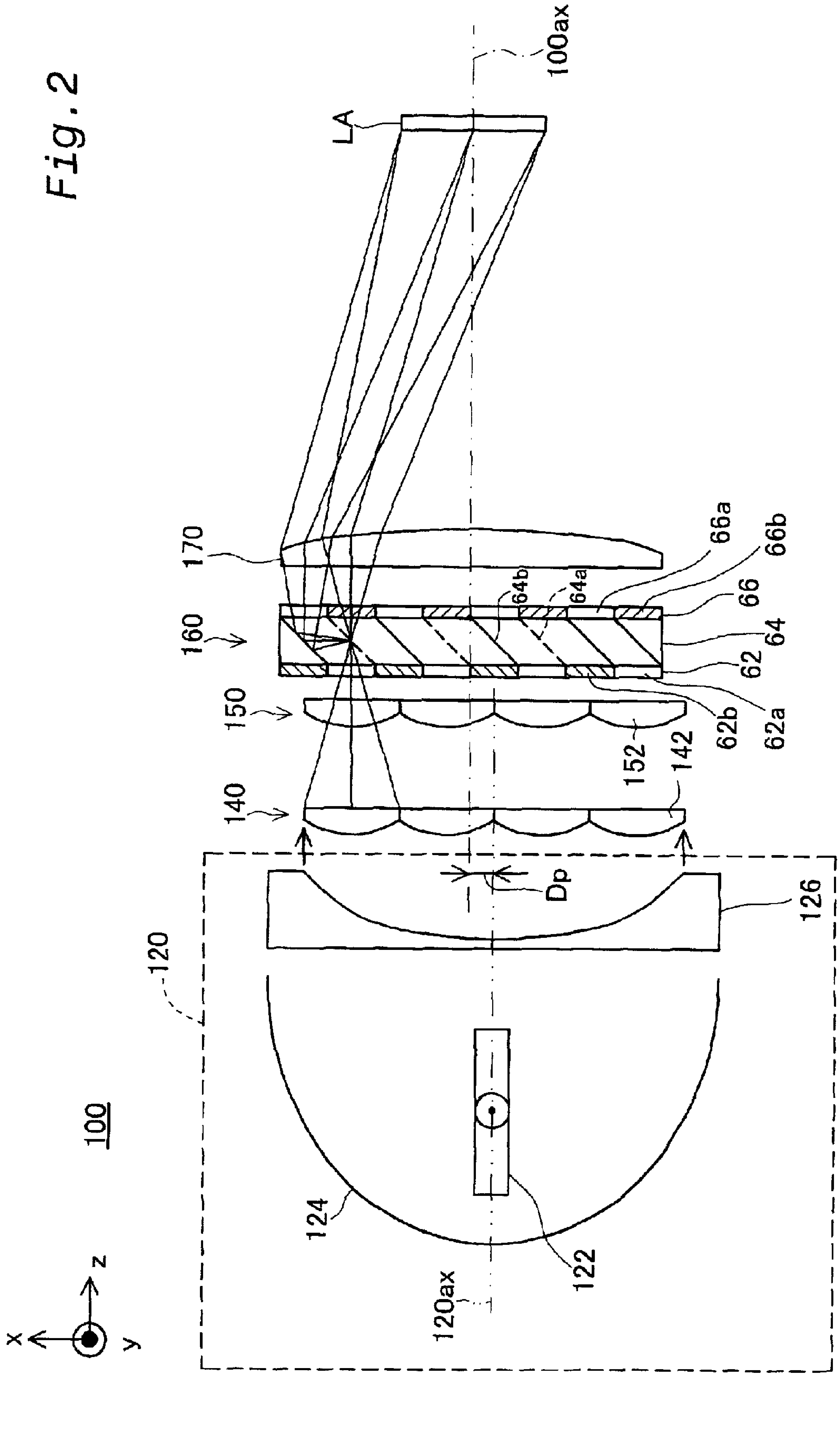


Fig. 1



1000
100
120
100ax
200
202
204
208
R
GB
G
B
220
222
224
226
228
230
232
234
300R
300G
300B
520
521
522
540
SC
x
y
z

Fig. 2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100ax
LA
170
160
150
140
66a
66b
66
64
62
64a
64b
62a
62b
152
142
Dp
120
126
124
122
120ax
x
y
z

Fig.3(A)

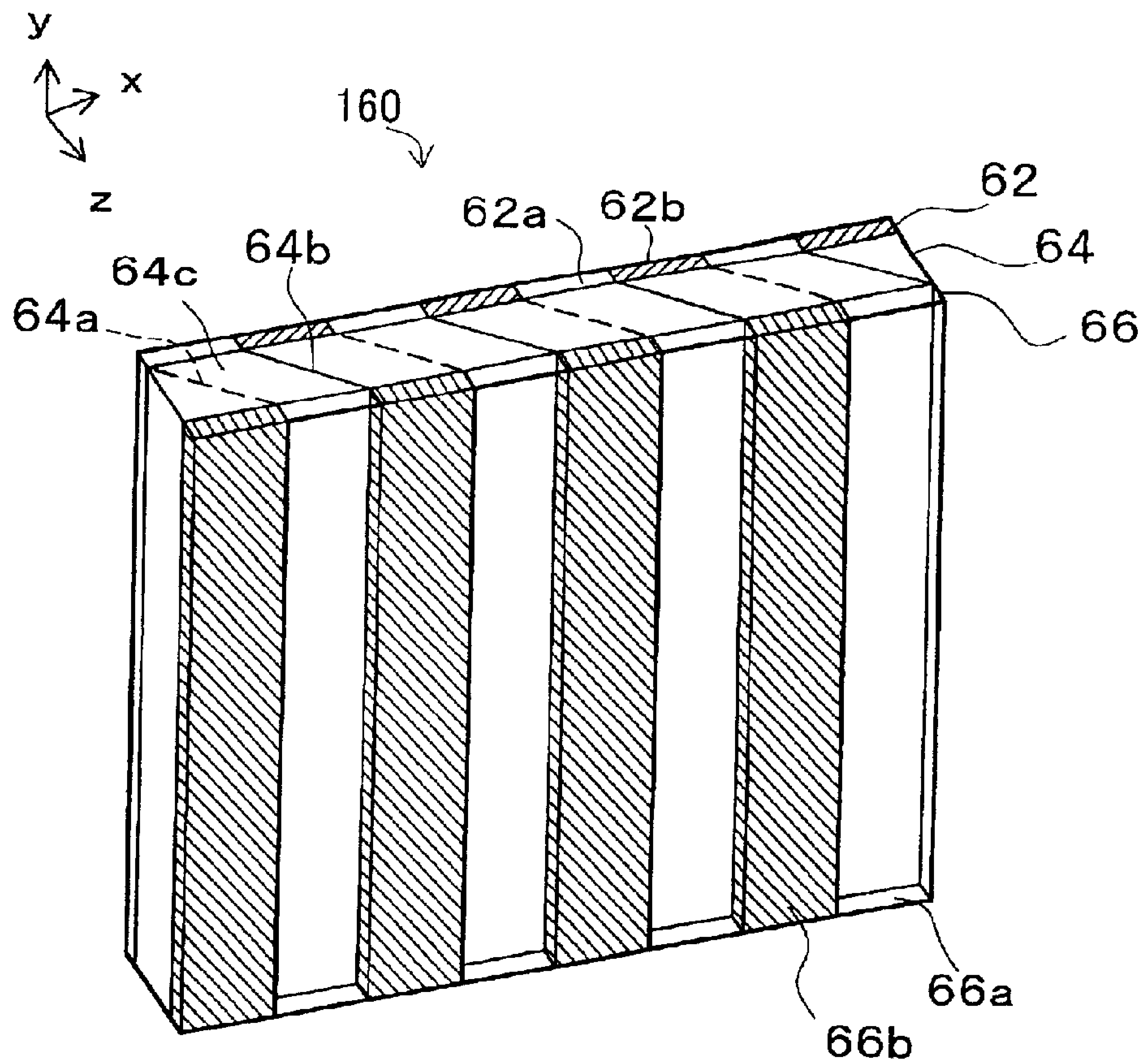

y
x
z
160
62
62a
62b
64
64b
64c
64a
66
66a
66b

Fig.3(B)

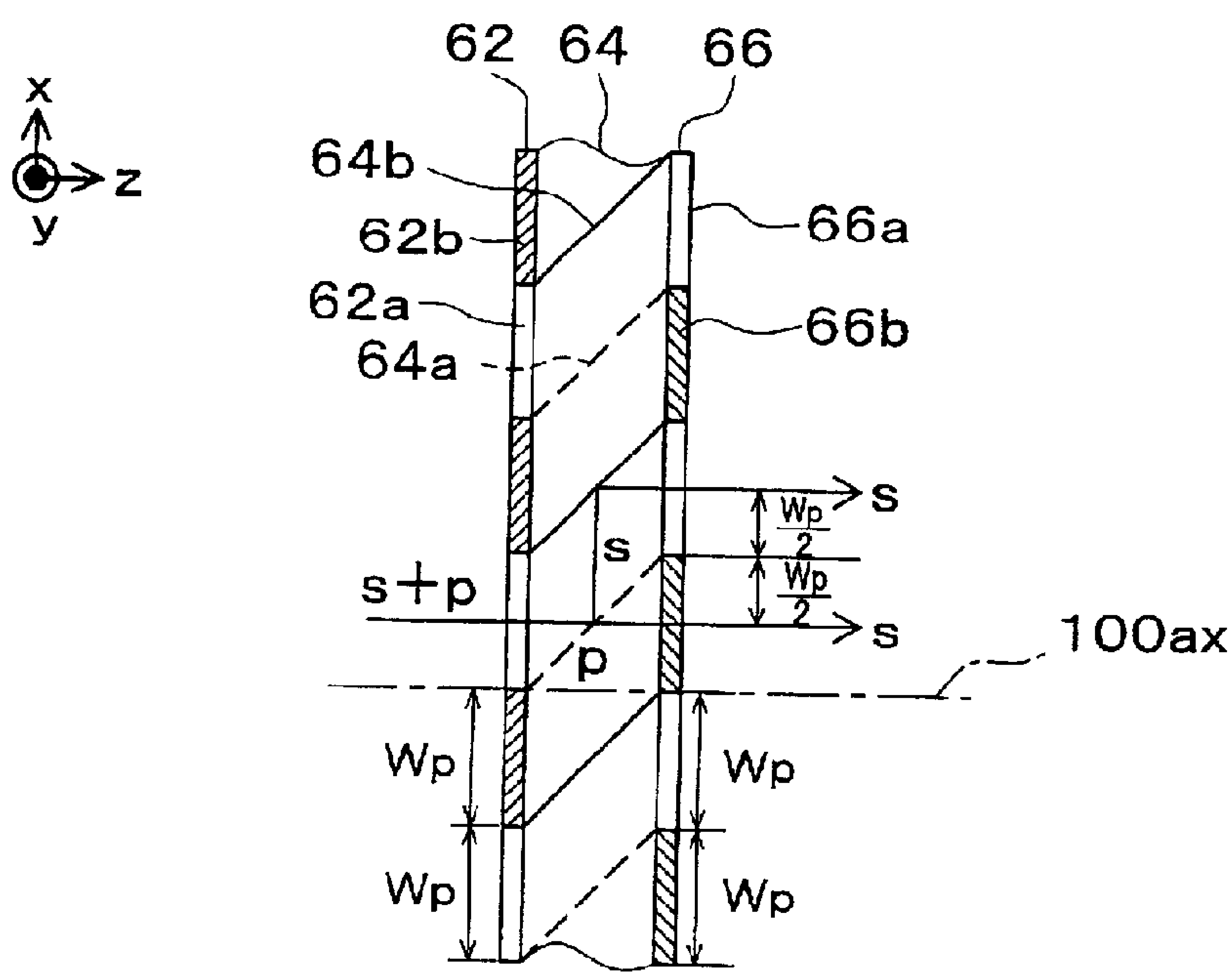
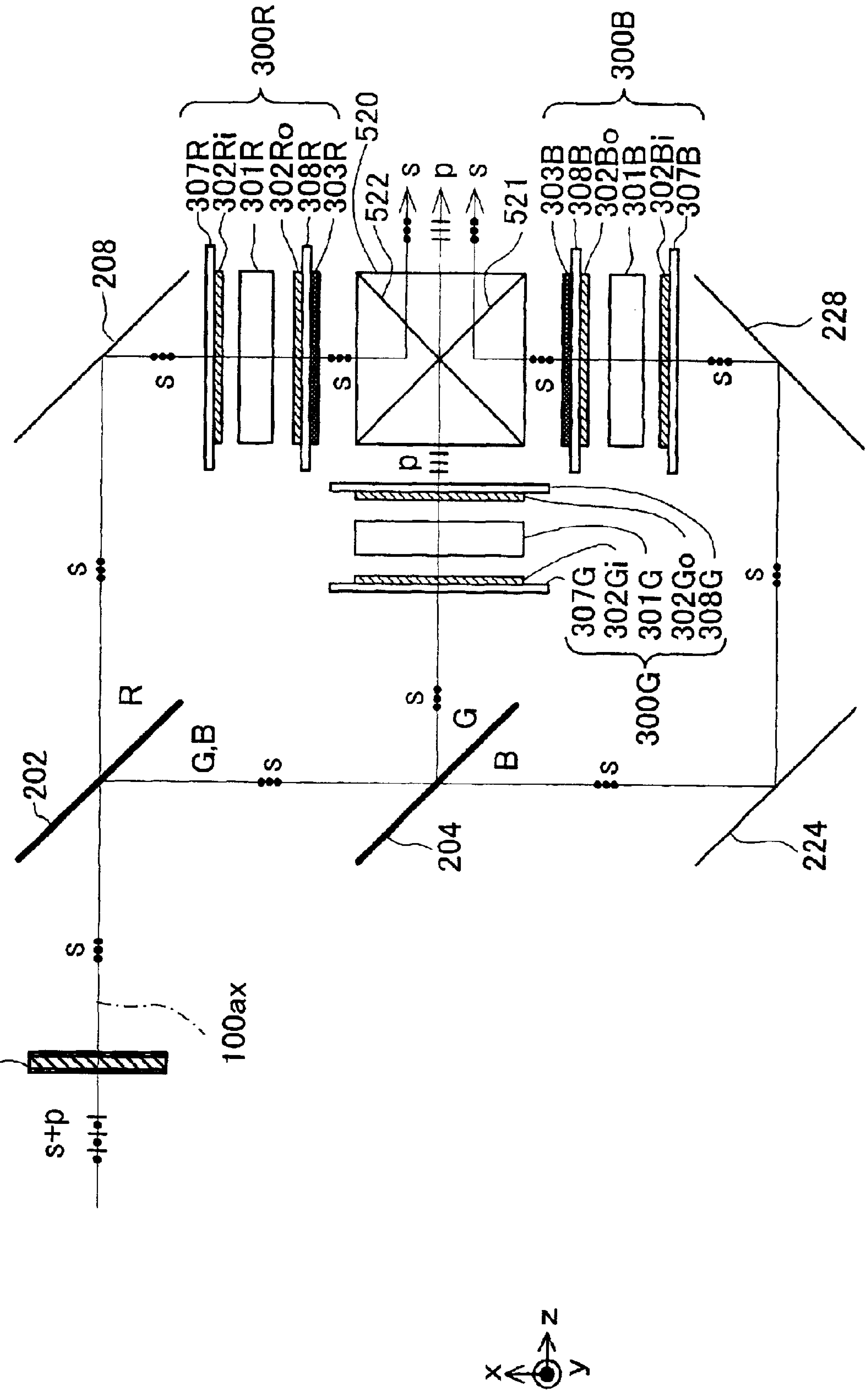

x
z
y
62
64
66
64b
62b
62a
64a
66a
66b
s
s+p
p
Wp/2
100ax
Wp

Fig. 4


300R
307R
302Ri
301R
302Ro
308R
303R
520
522
521
300B
303B
308B
302Bo
301B
302Bi
307B
208
228
202
204
224
R
G,B
G
B
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160
100ax
300G
307G
302Gi
301G
302Go
308G
x
y
z

Fig.5

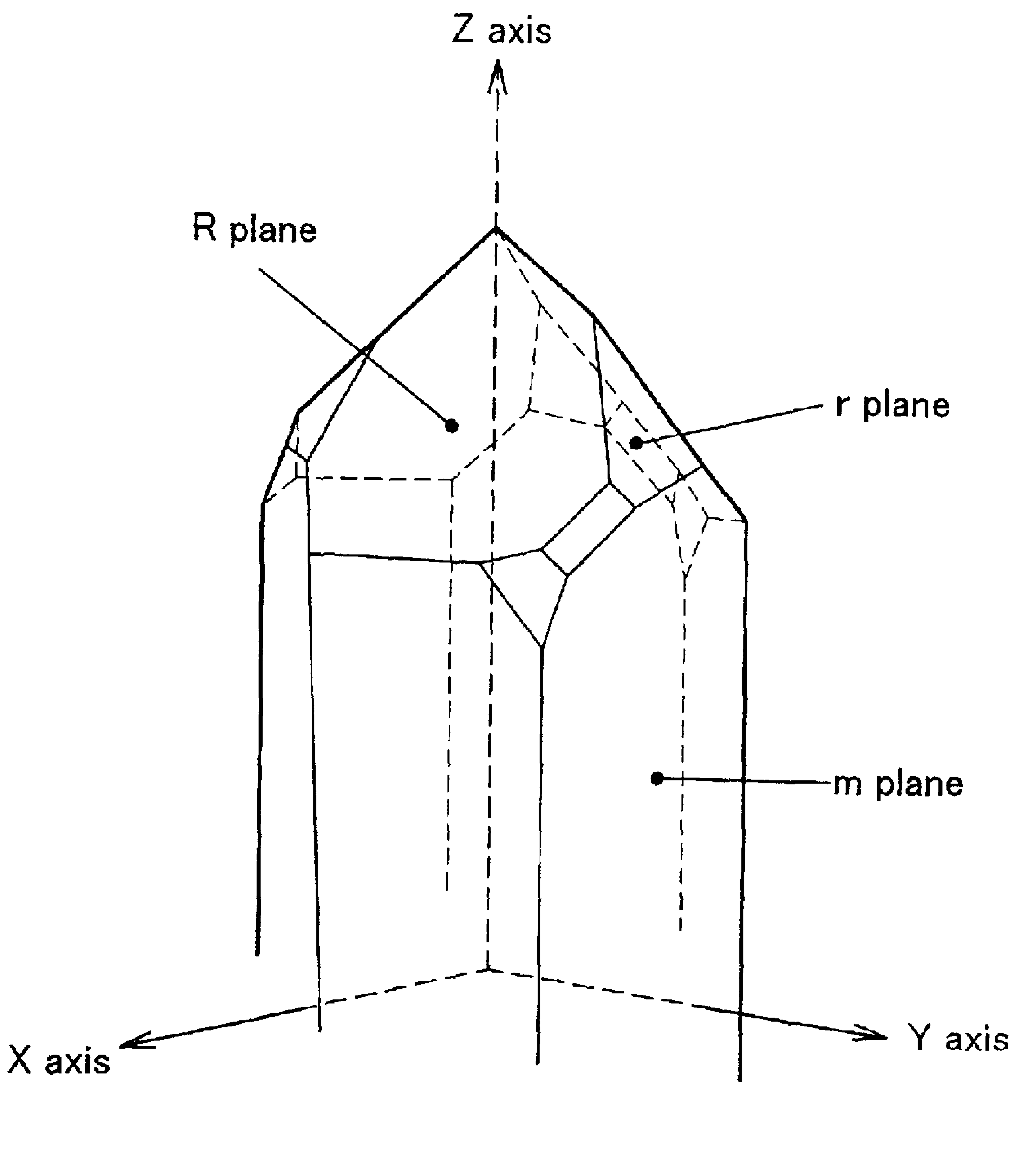


Fig.6(A)

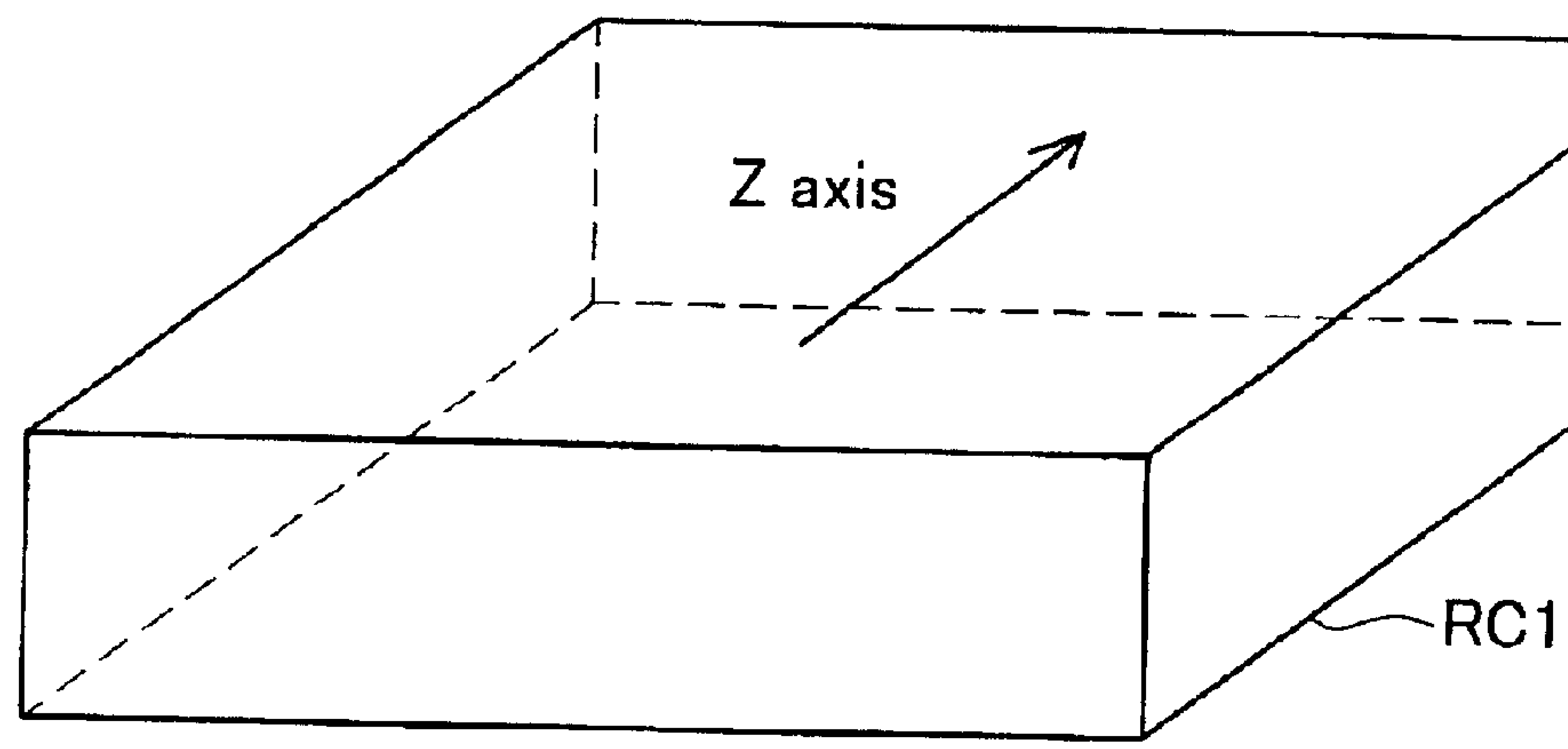


Fig.6(B)

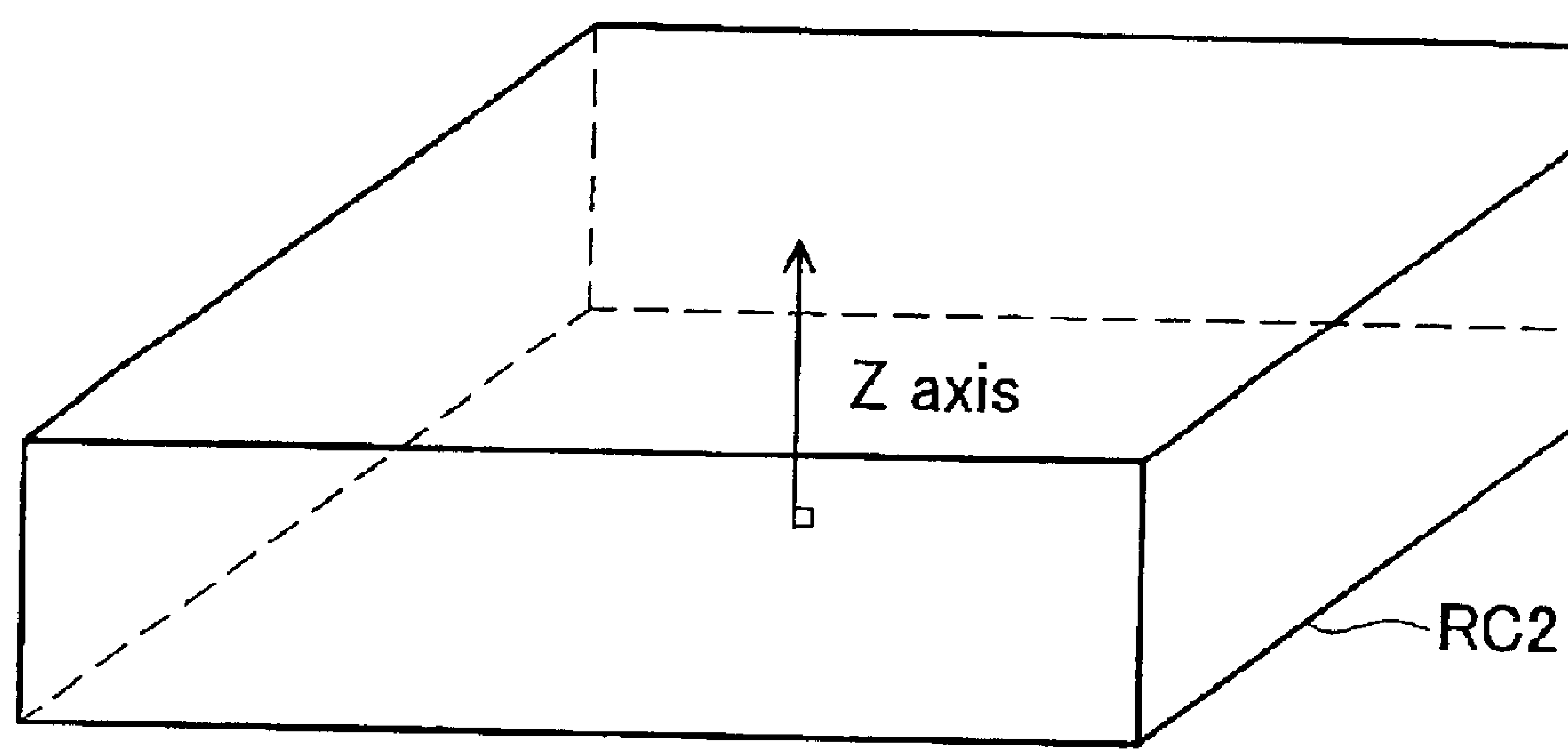


Fig.7(A)

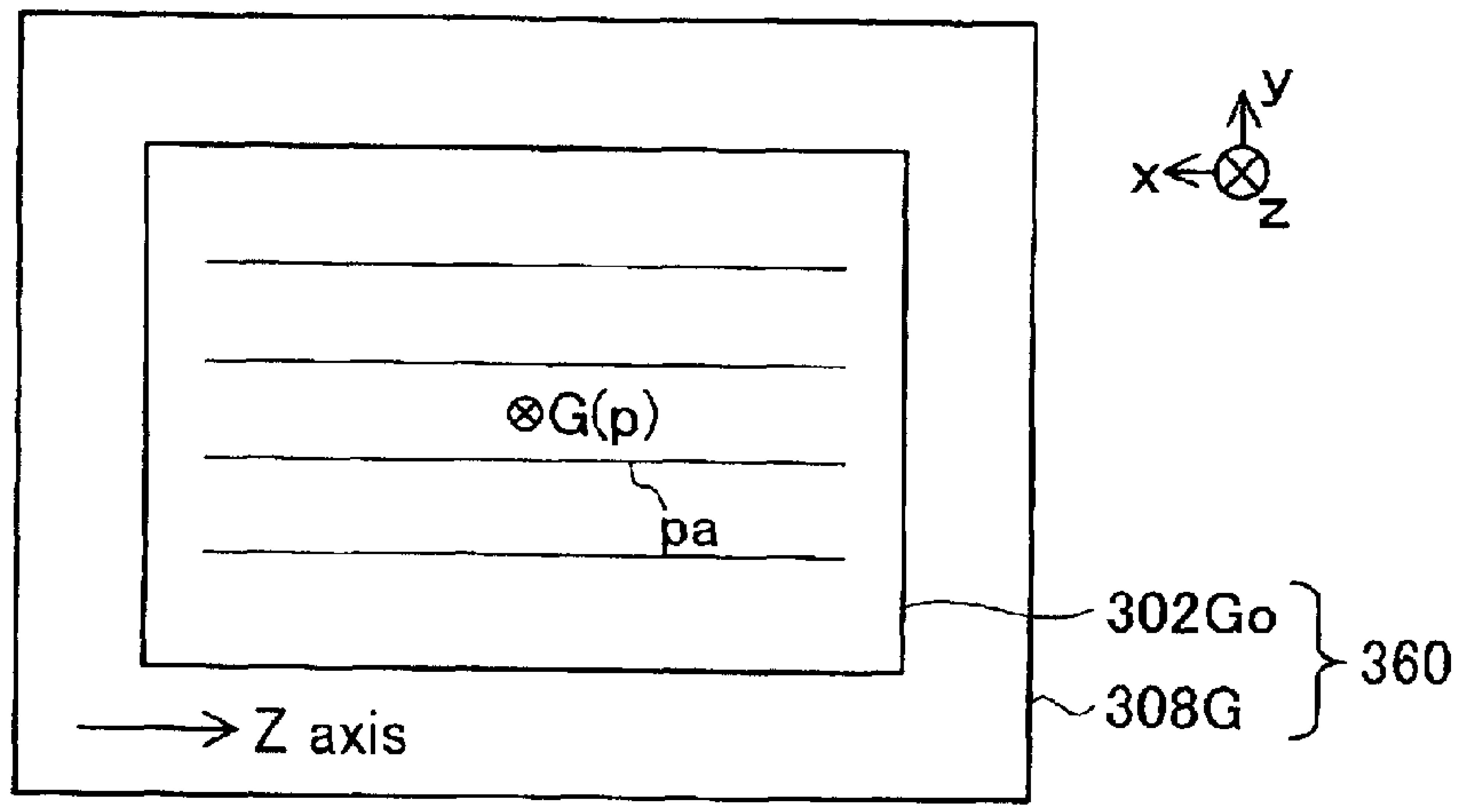


Fig.7(B)

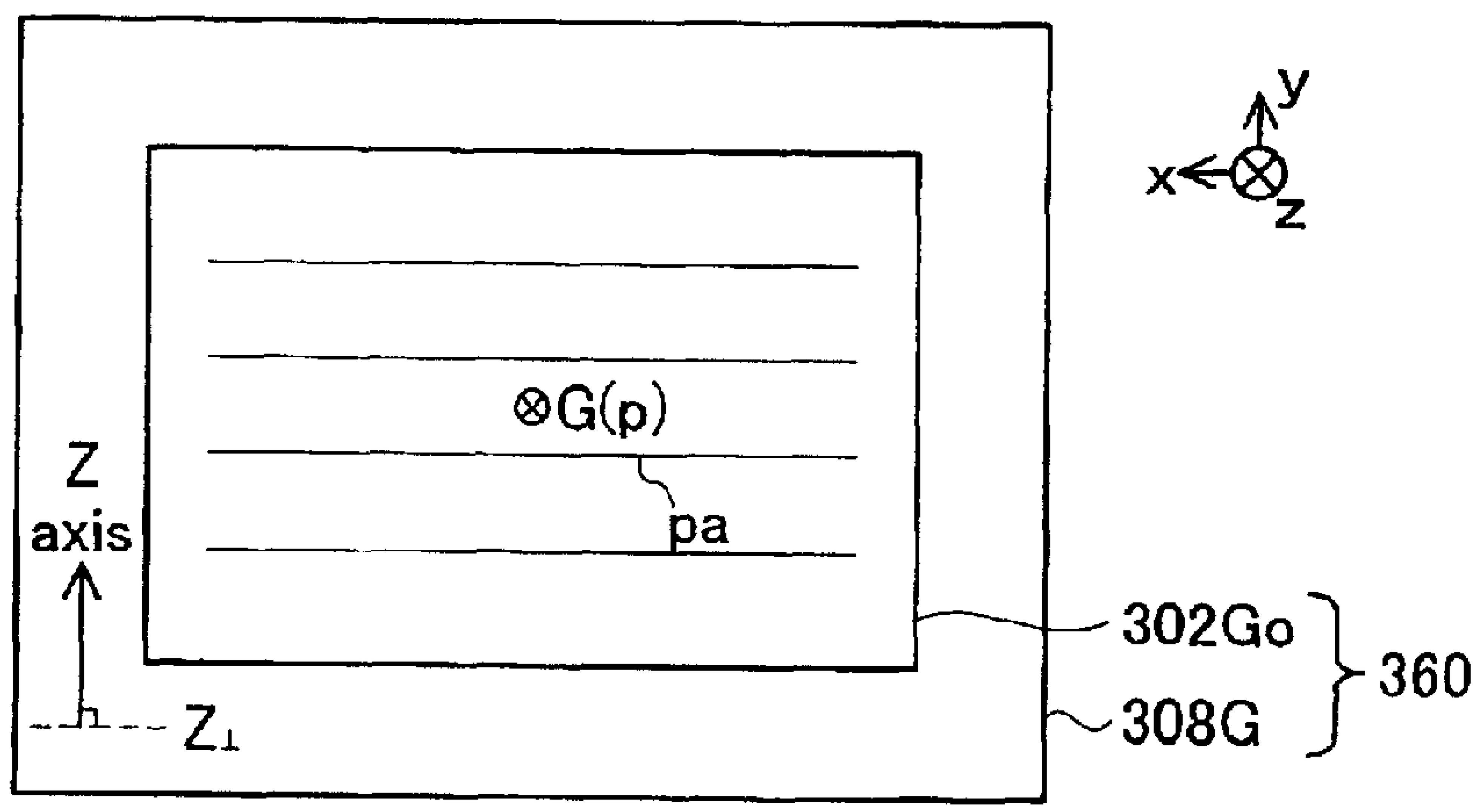


Fig.7(C)

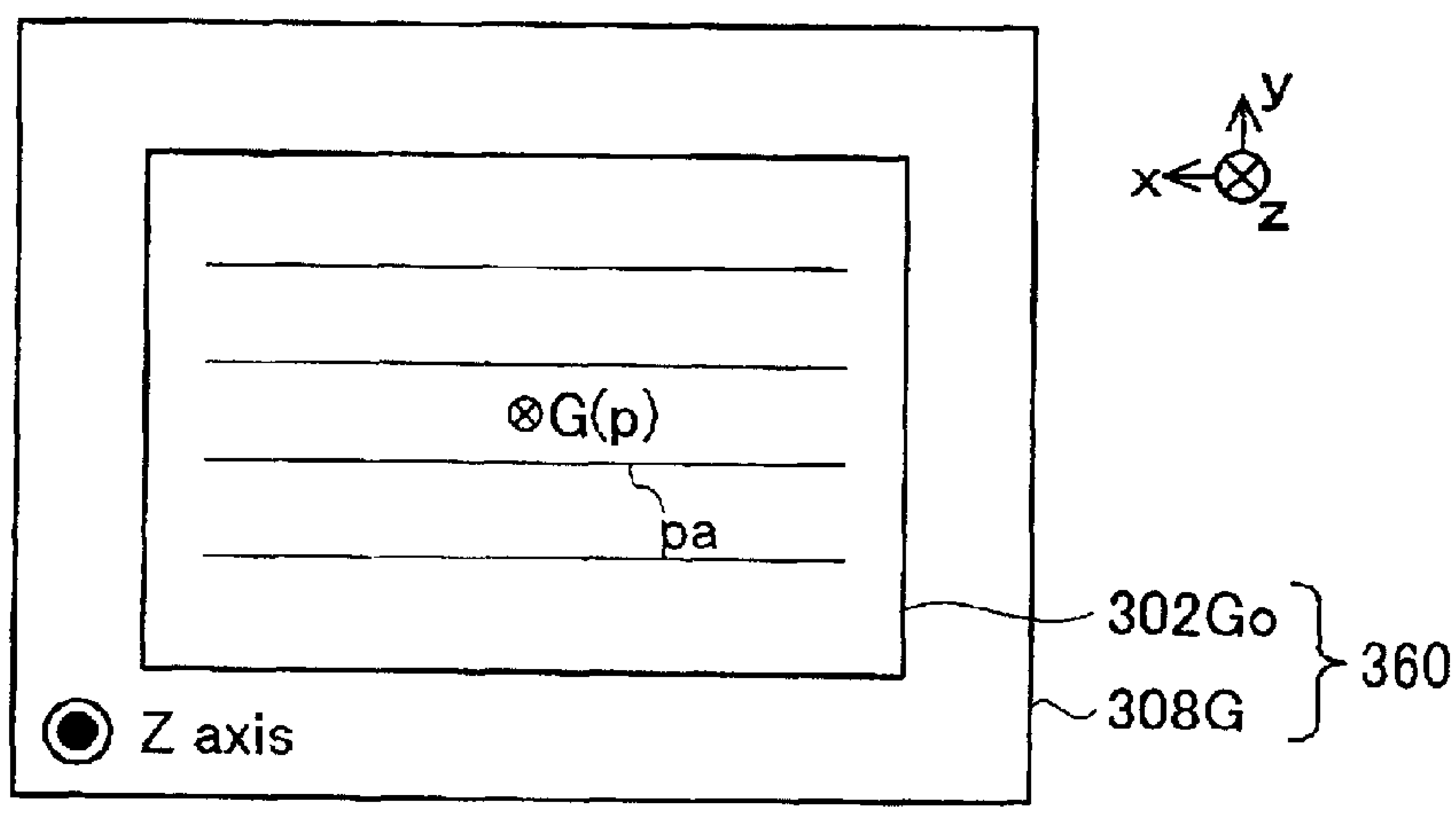


Fig. 8

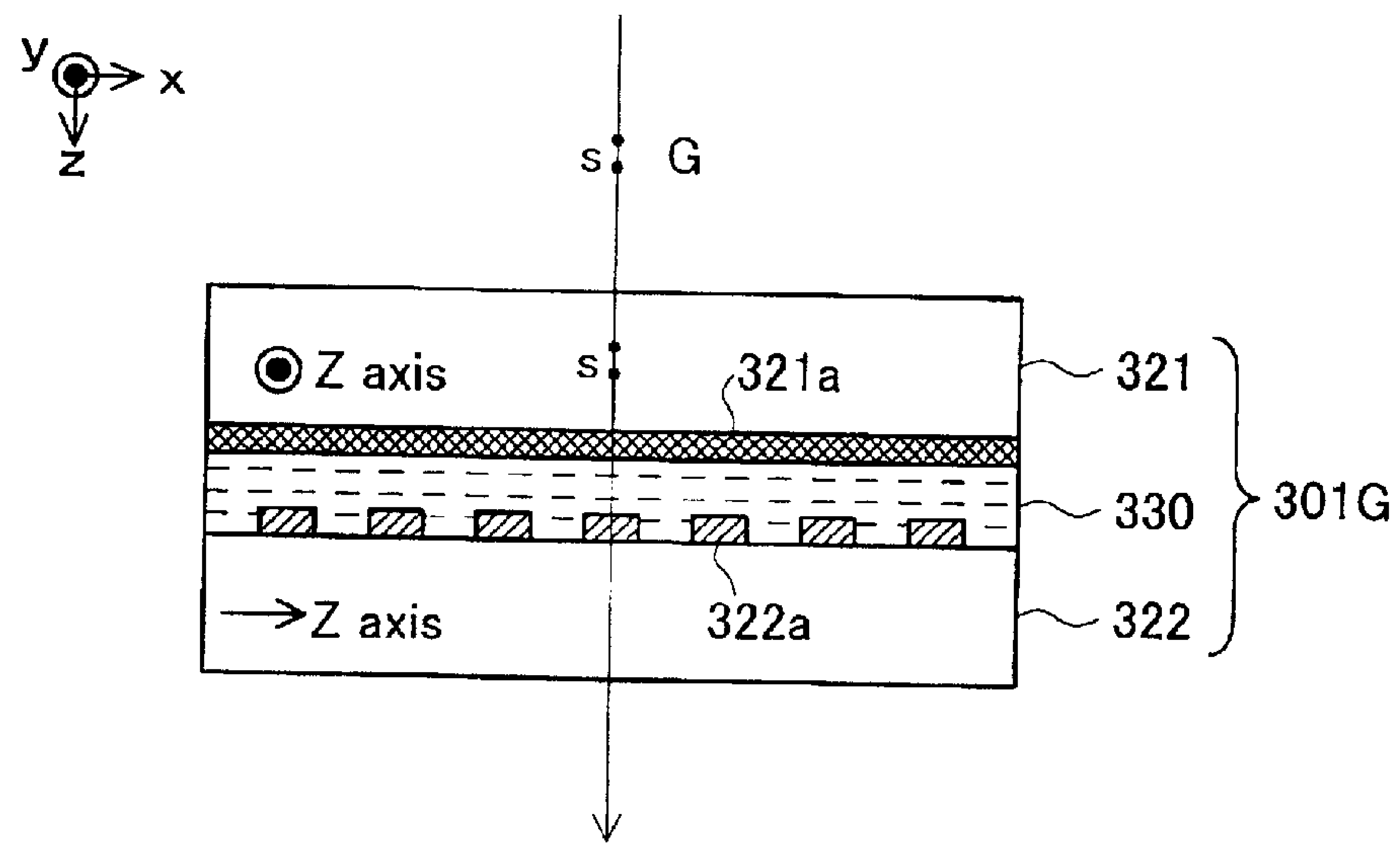

y
x
z
s
G
Z axis
s
321a
321
330
301G
Z axis
322a
322

Fig. 9

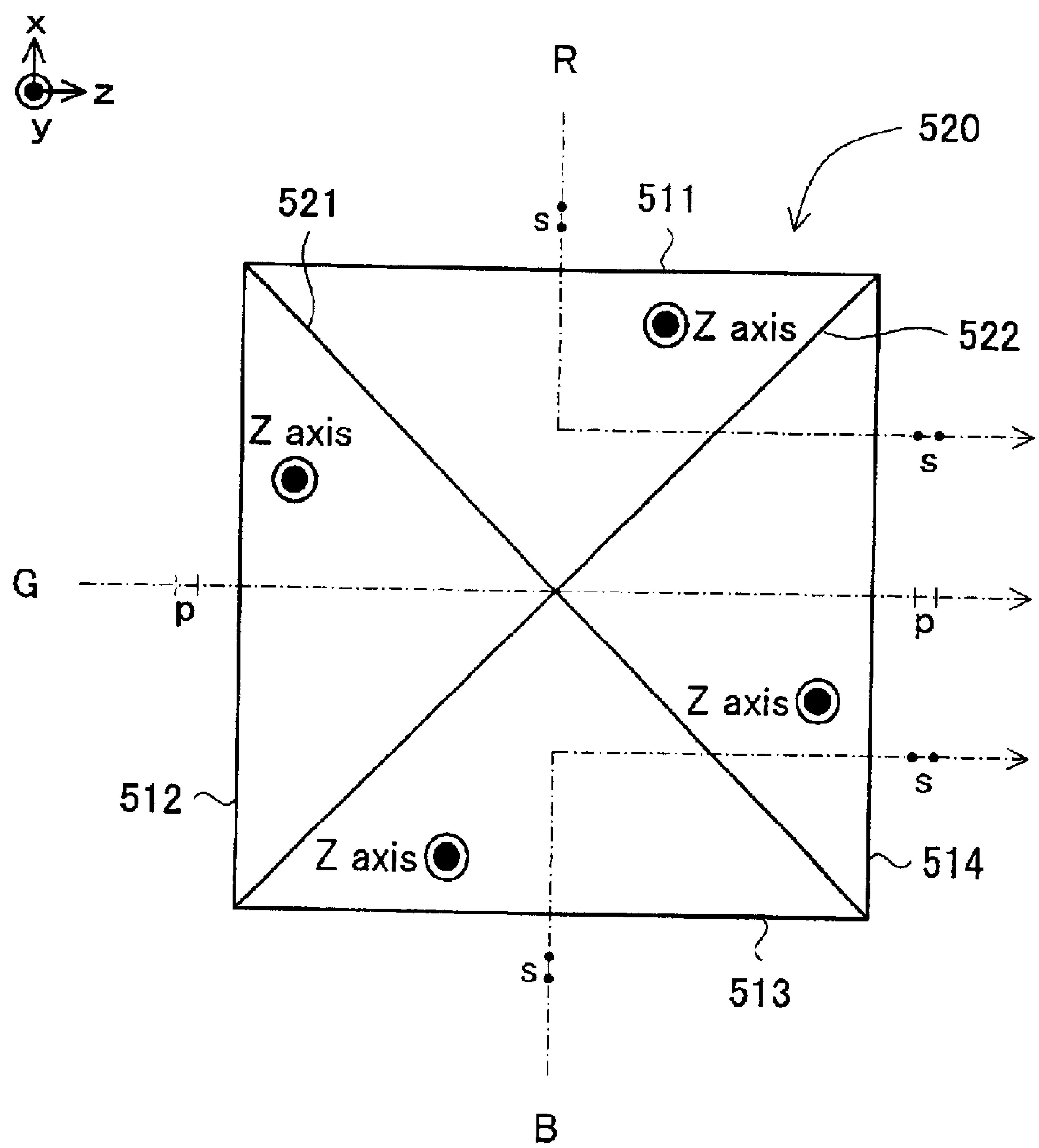

x
z
y
R
520
521
s
511
Z axis
522
Z axis
s
G
p
p
Z axis
512
s
Z axis
514
s
513
B

Fig. 10

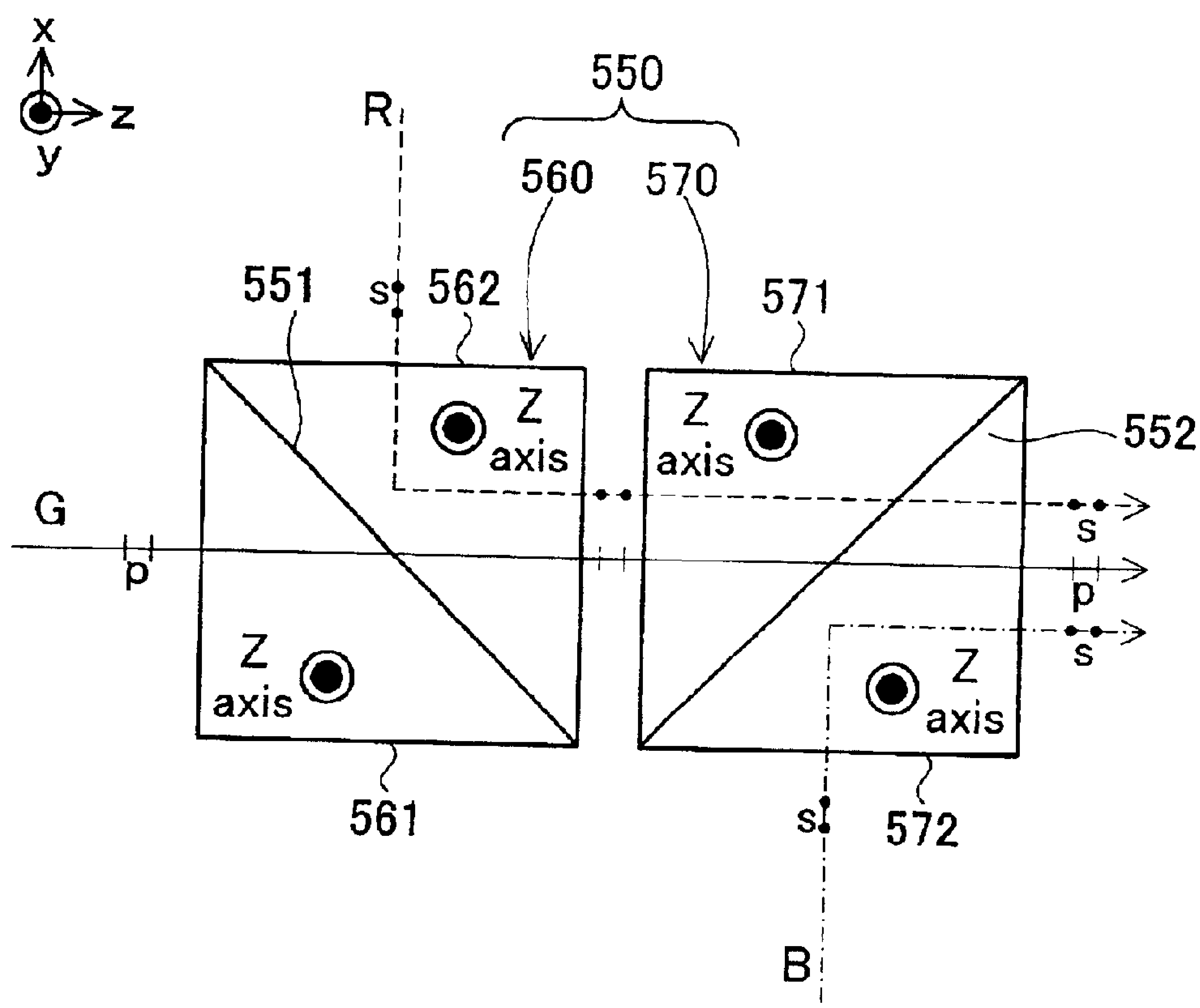


Fig. 11

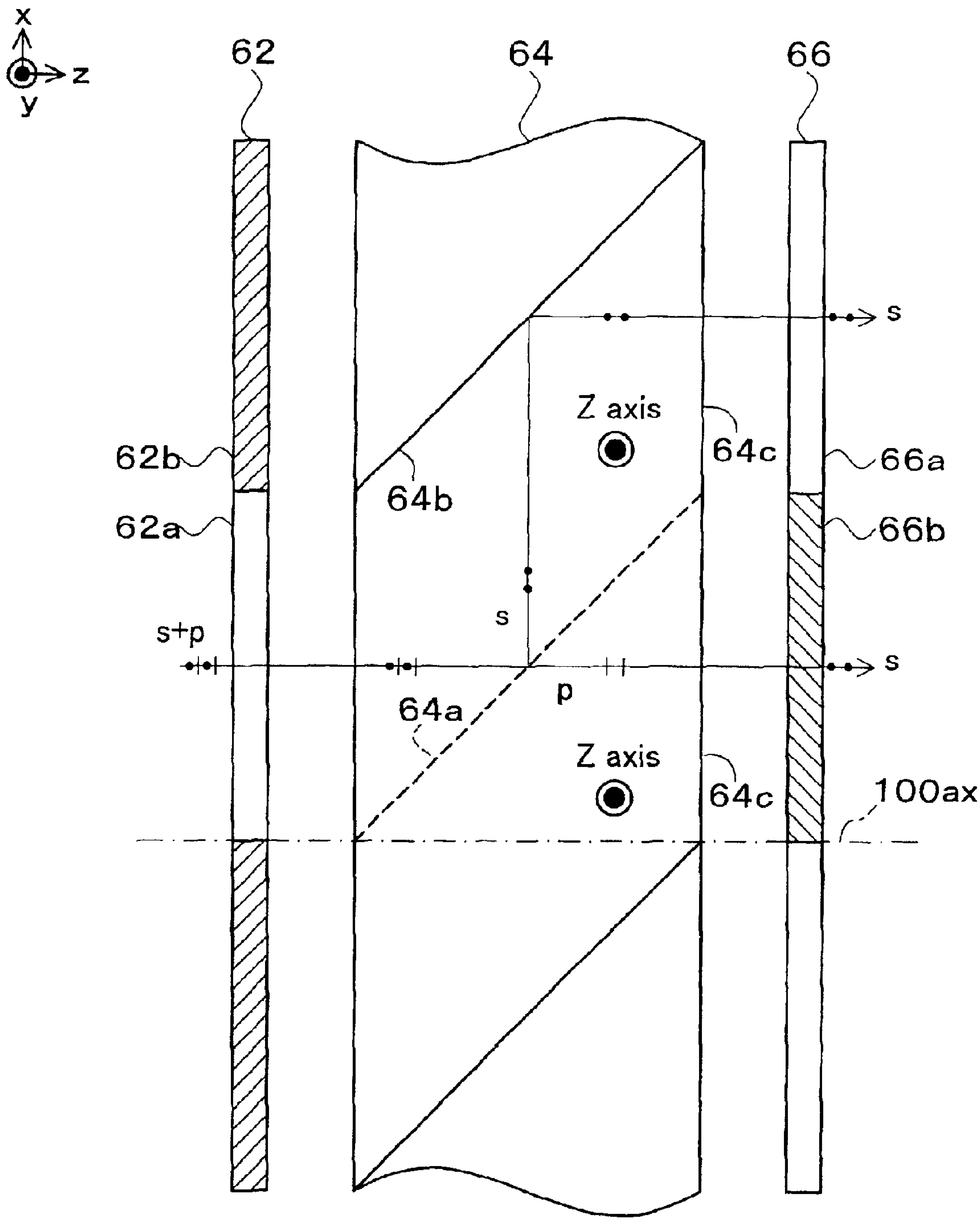

x
z
y
62
64
66
s
Z axis
64c
62b
66a
64b
62a
66b
s
s+p
s
p
64a
Z axis
64c
100ax

Fig. 12

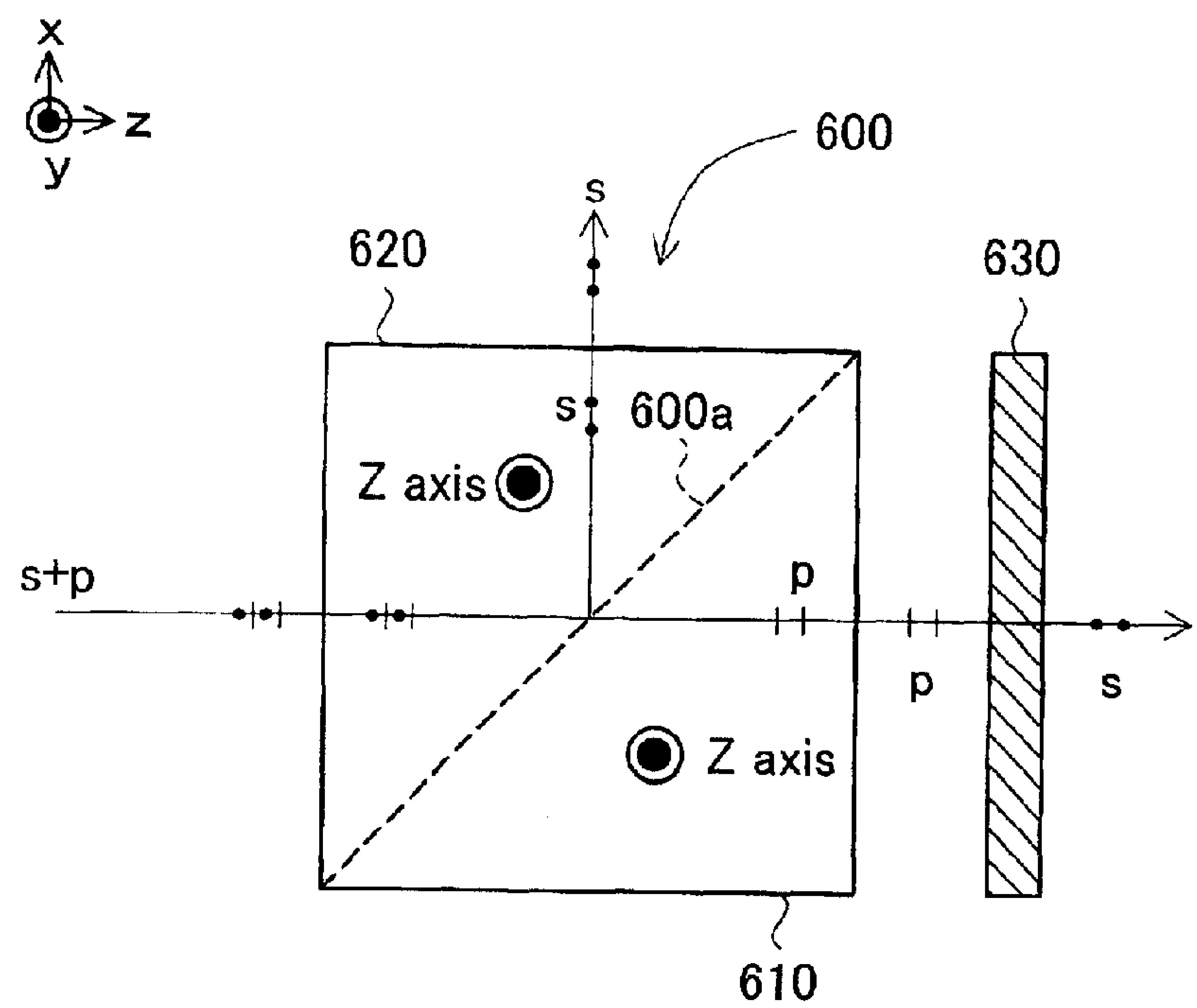
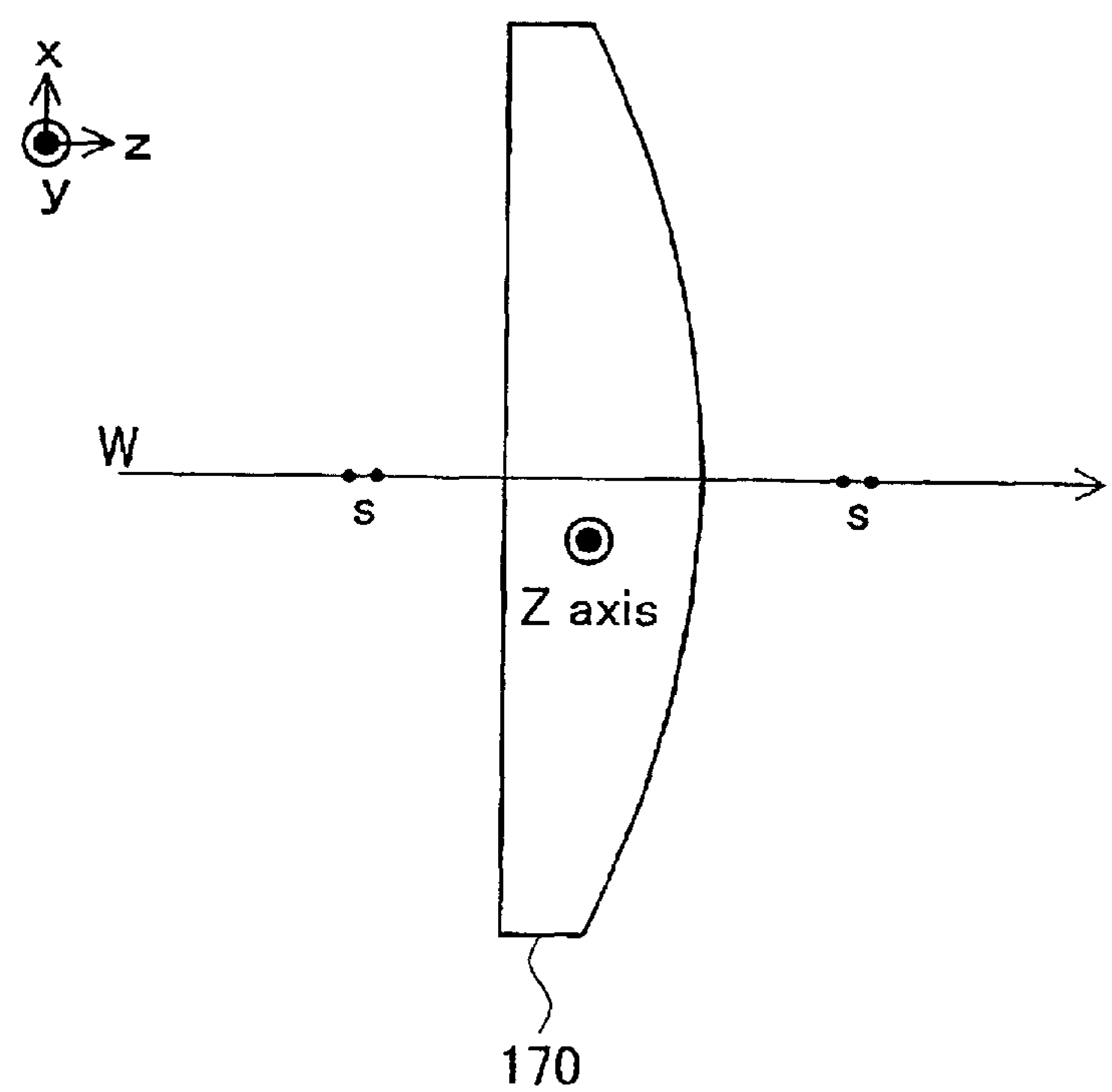

x
z
y
600
s
620
630
s
600a
Z axis
s+p
p
p
s
Z axis
610

Fig. 13


x
z
y
W
s
s
Z axis
170

PROJECTOR COMPRISING AN OPTICAL COMPONENT HAVING A ROCK CRYSTAL MEMBER

TECHNICAL FIELD

This invention relates to a projector for projecting and displaying images.

BACKGROUND ART

Projectors display images by modulating light from an illumination optical system in response to image information (image signal) by a liquid crystal light valve, and projecting the modulated light onto a screen.

The liquid crystal light valve generally includes a liquid crystal panel and polarizing plates arranged on a light incident side and a light exiting side of the liquid crystal panel. The polarizing plate functions to allow transmission of only a light component in the direction of a polarization axis, while cutting off the other light components. The light entering the liquid crystal light valve is thus modulated in response to image information.

The polarizing plate generates heat during cutting off the light other than the light component in the direction of the polarization axis. The generated heat raises the temperature of the polarizing plate and causes distortion and deterioration of the polarizing plate. The distorted and deteriorated polarizing plate mistakenly allows transmission of non-target light while cutting off non-target light. The polarizing plate is conventionally attached to a glass plate like crown glass called white plate glass. But recently, the polarizing plate is attached to a sapphire substrate having a relatively high thermal conductivity, so as to suppress the temperature rise of the polarizing plate.

Manufacture of the sapphire substrate is, however, relatively difficult, which makes it rather difficult to manufacture the projector. This is ascribed to difficulties in production and processing of sapphire. This problem is common to all the projectors utilizing the sapphire member.

DISCLOSURE OF THE INVENTION

The object of the present invention is thus to solve the drawbacks of the prior art discussed above and to provide a technique of readily manufacturing a projector.

At least part of the above and the other related objects is attained by a first apparatus of the present invention, which includes: an illumination optical system for emitting light; an electro-optical device for modulating the light emitted from the illumination optical system in response to image information; a projection optical system for projecting a modulated light generated by the electro-optical device; and an optical component having a rock crystal member composed of rock crystal, the optical component being located in an optical path including the illumination optical system and the projection optical system.

The first apparatus of the present invention has the optical component including the rock crystal member composed of rock crystal. The rock crystal member is more easily manufactured than the conventionally used sapphire member. This facilitates manufacture of the optical component including the rock crystal member and thereby manufacture of the projector. Rock crystal has a higher thermal conductivity than the conventionally used glass. Another advantage is thus to suppress a temperature rise of the optical component.

In one preferable application, the rock crystal member is disposed in such a manner that a Z axis of the rock crystal is substantially perpendicular to a center axis of a light passing through the rock crystal member.

In rock crystal, the thermal conductivity of a plane parallel to the Z axis is higher than the thermal conductivity of a plane perpendicular to the Z axis. The above arrangement thus further suppresses the temperature rise of the optical component and homogenizes an in-plane temperature distribution in a face perpendicular to the center axis of the light.

In this application, when the light passing through the rock crystal member is linearly polarized light, it is preferable that the rock crystal member is disposed in such a manner that the Z axis of the rock crystal is substantially parallel to or substantially perpendicular to an electric vector of the linearly polarized light.

This arrangement effectively ensures little variation in polarizing state when the linearly polarized light passes through the rock crystal, which is an optically uniaxial crystal.

In another preferable application, the rock crystal member is disposed in such a manner that a Z axis of the rock crystal is substantially parallel to a center axis of a light passing through the rock crystal member.

However, the polarizing state of light varies when the center axis of the light passing through the rock crystal member is not sufficiently parallel to the Z axis of the rock crystal. It is accordingly preferable that such a rock crystal member is disposed at a position that hardly utilizes specified polarized light such as the linearly polarized light or at a position that is hardly affected by the variation in polarizing state.

In one preferable embodiment of the above apparatus, the optical component has: a rock crystal substrate as the rock crystal member; and an optical element provided on the rock crystal substrate, and a Z axis of the rock crystal substrate is set to be substantially parallel to a surface of the substrate.

In this case, the heat of the optical element is transmitted parallel to the surface of the rock crystal substrate. This further suppresses the temperature rise of the optical component and homogenizes an in-plane temperature distribution of the optical component.

In this embodiment, it is preferable that the optical element is a polarizing plate, and the polarizing plate is provided on the rock crystal substrate in such a manner that a polarization axis of the polarizing plate is substantially parallel to or substantially perpendicular to a Z axis of the rock crystal.

In this arrangement, when the light output from the polarizing plate enters the rock crystal substrate, the polarizing state of the linearly polarized light output from the polarizing plate will be kept. On the other hand, when the light output from the rock crystal substrate enters the polarizing plate, only a predetermined linearly polarized light will be output by means of the polarizing plate. In the latter case, when the linearly polarized light enters the rock crystal substrate, the incident linearly polarized light will enter the polarizing plate with little variation in polarizing state.

In another preferable embodiment of the above apparatus, the optical component has: a rock crystal substrate as the rock crystal member; and an optical element provided on the rock crystal substrate, and a Z axis of the rock crystal substrate is set to be substantially perpendicular to a surface of the substrate.

However, the polarizing state of light varies when the center axis of the light passing through the rock crystal member is not sufficiently parallel to the Z axis of the rock crystal. It is accordingly preferable that such a rock crystal member is disposed at a position that hardly utilizes specified polarized light such as the linearly polarized light or at a position that is hardly affected by the variation in polarizing state.

In the above apparatus, it is preferable that the electro-optical device has a pair of substrates, at least one of the pair of substrates is a rock crystal substrate as the rock crystal member, and a Z axis of the rock crystal substrate is set to be substantially parallel to or substantially perpendicular to a surface of the substrate.

This arrangement effectively suppresses a temperature rise of the electro-optical device.

In the above apparatus, the rock crystal member may be a lens.

This arrangement effectively suppresses a temperature rise of the lens. In the structure that another optical element is attached to or arranged close to the lens, a temperature rise of the optical element will be also suppressed.

In one preferable application of the above apparatus, the illumination optical system may include a polarized light generation section for emitting a predetermined polarized light. The polarized light generation section may include: the optical component for dividing an incident light into two different polarized lights; and a selective retardation plate for adjusting one of the two polarized lights output from the optical component to the other. The optical component may include: a plurality of the rock crystal members arrayed in a predetermined direction; and a polarization separation film and a reflection film that are alternately arranged on interfaces of the plurality of rock crystal members.

In another preferable application of the above apparatus, the illumination optical system may include a polarized light generation section for emitting a predetermined polarized light. The polarized light generation section may include: the optical component for dividing an incident light into two different polarized lights; and a selective retardation plate for adjusting one of the two polarized lights output from the optical component to the other. The optical component may include: the rock crystal member; and a polarization separation film formed on the rock crystal member.

Either of the above applications desirably suppresses a temperature rise of the optical component. In the structure that a retardation plate is attached to the optical component, a temperature rise of the retardation plate will be also suppressed.

The present invention is also directed to a second apparatus, which includes: an illumination optical system for emitting light; a color light separation optical system that divides the light emitted from the illumination optical system into first through third color lights respectively having three color components; first through third electro-optical devices that modulate the first through the third color lights divided by the color separation optical system in response to image information, so as to generate first through third modulated lights; a color light composition optical system for combining the first through the third modulated lights; a projection optical system for projecting composite light output from the color light composition optical system; and an optical component having a rock crystal member composed of rock crystal, the optical component being located in an optical path including the illumination optical system and the projection optical system.

The second apparatus of the present invention has the optical component including the rock crystal member composed of rock crystal and thereby exerts the similar functions and advantages to those of the first apparatus.

In one preferable application of the above apparatus, at least one of the color light separation optical system and the color light composition optical system may include the optical component. The optical component may include: the four columnar rock crystal members divided by a substantially X-shaped interface; and a selector film formed on the interface to select light having wavelength in a predetermined range.

In another preferable application of the above apparatus, at least one of the color light separation optical system and the color light composition optical system may include the optical component. The optical component may include: the rock crystal member; and a selector film formed on the rock crystal member to select light having wavelength in a predetermined range.

These arrangement desirably suppresses a temperature rise of the optical component. Especially when an optical element, such as a polarizing plate or a retardation plate, is attached to the optical component, the arrangement also suppresses a temperature rise of the optical element.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a projector in one embodiment of the present invention;

FIG. **2** is an enlarged view illustrating the illumination optical system **100** shown in FIG. **1**;

FIGS. **3**(A) and **3**(B) illustrate the polarized light generation optical system **160**;

FIG. **4** illustrates the main part of the projector **1000** shown in FIG. **1**;

FIG. **5** illustrates the crystal structure of rock crystal;

FIGS. **6**(A) and **6**(B) illustrate the rock crystal substrate used in the embodiment;

FIGS. **7**(A) through **7**(C) illustrate an optical component **360** provided on the light exiting side of the second liquid crystal light valve **300**G (FIG. **4**);

FIG. **8** schematically illustrates the optical component (liquid crystal panel) **301**G included in the second liquid crystal light valve **300**G (FIG. **4**);

FIG. **9** is an enlarged view illustrating the optical component (cross dichroic prism) **520** provided as the color light composition optical system (FIG. **4**);

FIG. **10** illustrates another dichroic prism **550**;

FIG. **11** is an enlarged view illustrating the optical component (polarization beam splitter array) **64** included in the illumination optical system **100** (FIG. **2**);

FIG. **12** illustrates a polarization beam splitter; and

FIG. **13** illustrates the optical component (superimposing lens) **170** included in the illumination optical system **100** (FIG. **2**).

BEST MODE FOR CARRYING OUT THE INVENTION

A. General Structure of Projector

One mode of carrying out the present invention is discussed below as a preferred embodiment. FIG. **1** illustrates a projector in one embodiment of the present invention. A projector **1000** comprises: an illumination optical system **100** including a light source device **120**; a color light separation optical system **200**; a relay optical system **220**;

three liquid crystal light valves **300**R, **300**G and **300**B; a cross dichroic prism **520**; and a projection lens **540**.

Light emitted from the illumination optical system **100** (FIG. **1**) is separated into three color lights red (R), green (G), and blue (B) by the color light separation optical system **200**. The respective separated color lights are modulated in response to image information by the liquid crystal light valves **300**R, **300**G, and **300**B. The modulated color lights are combined to composite light by the cross dichroic prism **520**, and a resulting color image is projected and displayed on a screen SC by the projection lens **540**.

FIG. **2** is an enlarged view illustrating the illumination optical system **100** shown in FIG. **1**. The illumination optical system **100** comprises: the light source device **120**; first and second lens arrays **140** and **150**; a polarized light generation optical system **160**; and a superimposing lens **170**. The light source device **120** and the first and second lens arrays **140**, **150** are aligned along to a light source optical axis **120***ax*. The polarized light generation optical system **160** and the superimposing lens **170** are, on the other hand, aligned along to a system optical axis **100***ax*. The light source optical axis **120***ax* represents the center axis of a light emitted from the light source device **120**, and the system optical axis **100***ax* represents the center axis of a light emitted from an optical element after the polarized light generation optical system **160**. As illustrated, the system optical axis **100***ax* and the light source optical axis **120***ax* are shifted substantially in parallel in the x direction by a predetermined deviation Dp. The deviation Dp will be discussed later. A lighting area LA illuminated with the illumination optical system **100** in FIG. **2** corresponds to the liquid crystal light valves **300**R, **300**G, and **300**B of FIG. **1**.

The light source device **120** functions to emit a substantially parallel light. The light source device **120** includes an arc tube **122**, a reflector **124** having a concave face of ellipsoid of revolution, and a paralleling lens **126**. Light emitted from the arc tube **122** are reflected by the reflector **124**, and the reflected light is converted into a light substantially parallel to the light source optical axis **120***ax* by means of the paralleling lens **126**. A reflector having a concave face of paraboloid of revolution may be applicable for the light source device.

The first lens array **140** has a plurality of small lenses **142** arranged in a matrix. Each small lens **142** is a plano-convex lens, and its outer shape seen from the z direction is set to be similar to the lighting area LA (the liquid crystal light valve). The first lens array **140** divides the substantially parallel light emitted from the light source device **120** into a plurality of sub-beams.

Like the first lens array **140**, the second lens array **150** has a plurality of small lenses **152** arranged in a matrix. The second lens array **150** functions to adjust the respective center axes of the sub-beams output from the first lens array **140** to be substantially parallel to the system optical axis **100***ax*.

The sub-beams output from the respective small lenses **142** of the first lens array **140** are condensed via the second lens array **150** in the vicinity of it, or in the polarized light generation optical system **160**.

FIGS. **3**(A) and **3**(B) illustrate the polarized light generation optical system **160**. FIG. **3**(A) is a perspective view illustrating the polarized light generation optical system **160**, and FIG. **3**(B) is a plan view illustrating part of the polarized light generation optical system **160** seen from the +y direction. The polarized light generation optical system **160** includes a shading plate **62**, a polarization beam splitter array **64**, and a selective retardation plate **66**. The polarized light generation optical system **160** corresponds to the polarized light generation section of the present invention.

As shown in FIG. **3**(A), the polarization beam splitter array **64** is constructed by joining a plurality of columnar transmissive members **64***c* having a practically parallelogrammatic cross section. Polarization separation films **64***a* and reflection films **64***b* are alternately formed on the interfaces of the transmissive members **64***c*. A dielectric multi-layered film is used for the polarization separation film **64***a*, while a dielectric multi-layered film or a metal film is used for the reflection film **64***b*.

The shading plate **62** has shading faces **62***b* and open faces **62***a* arranged in stripe. The shading plate **62** shields the light that enter the shading faces **62***b*, while allowing passage of the light that enter the open faces **62***a*. The shading faces **62***b* and the open faces **62***a* are arranged to cause the sub-beams output from the first lens array **140** (FIG. **2**) not to enter the reflection films **64***b* but to enter only the polarization separation films **64***a* of the polarization beam splitter array **64**. More specifically, the center of each open face **62***a* of the shading plate **62** is substantially coincident with the center of each polarization separation film **64***a* of the polarization beam splitter array **64** as shown in FIG. **3**(B). An opening width Wp of the open face **62***a* in the x direction is set to be substantially equal to the dimension of the polarization separation film **64***a* in the x direction. Under such conditions, each sub-beam passing through the open face **62***a* of the shading plate **62** does not enter the reflection film **64***b* but enters only the polarization separation film **64***a*. The shading plate **62** may be produced by partly forming a shading film (for example, a chromium film, an aluminum film, or a dielectric multi-layered film) on a flat transparent body (for example, a glass plate). The shading plate **62** may otherwise be a shading flat plate, such as an aluminum plate, with openings.

Each sub-beam output from the first lens array **140** (FIG. **2**) has a principal ray (center axis) substantially parallel to the system optical axis **100***ax*, which enters the open face **62***a* of the shading plate **62** as shown by the solid line in FIG. **3**(B). The sub-beam passing through the open face **62***a* enters the polarization separation film **64***a*. The polarization separation film **64***a* divides the incident sub-beam into an s-polarized sub-beam and a p-polarized sub-beam. The p-polarized sub-beam is transmitted through the polarization separation film **64***a*, whereas the s-polarized sub-beam is reflected by the polarization separation film **64***a*. The s-polarized sub-beam reflected by the polarization separation film **64***a* goes to the reflection film **64***b* and is further reflected by the reflection film **64***b*. The p-polarized sub-beam transmitted through the polarization separation film **64***a* is virtually parallel to the s-polarized sub-beam reflected by the reflection film **64***b*.

The selective retardation plate **66** has open layers **66***a* and $\lambda/2$ retardation layers **66***b*. Each open layer **66***a* allows transmission of incident linear polarized light. Each $\lambda/2$ retardation layer **66***b* has the function of a polarization conversion element that converts the incident linear polarized light into linear polarized light having an orthogonal polarization direction. In this embodiment, as shown in FIG. **3**(B), the p-polarized sub-beam transmitted through the polarization separation film **64***a* enters the $\lambda/2$ retardation layer **66***b*. The p-polarized sub-beam is accordingly converted to the s-polarized sub-beam by the $\lambda/2$ retardation layer **66***b*. On the other hand, the s-polarized sub-beam reflected by the reflection film **64***b* enters the open layer **66***a* and is output without any change as the s-polarized sub-beam. Each non-polarized sub-beam entering the polarized light generation optical system **160** is thus converted to and output as the s-polarized sub-beam. In one applicable modification, the λ/2 retardation layers **66***b* are disposed only on the exiting faces of the s-polarized sub-beam reflected by the reflection films **64***b*. This arrangement enables each sub-beam entering the polarized light generation optical system **160** to be converted to and output as the p-polarized sub-beam. The selective retardation plate **66** may have vacancy at positions corresponding to the open layers **66***a* and simply include the λ/2 retardation layers **66***b* bonded to the exiting faces of either the p-polarized sub-beams or the s-polarized sub-beams.

As clearly understood from FIG. **3**(B), the center of two s-polarized lights output from the polarized light generation optical system **160** is deviated from the center of the incident non-polarized light (s-polarized light+p-polarized light) in the +x direction. This deviation is equal to half the width Wp of the λ/2 retardation layer **66***b* (that is, the dimension of the polarization separation film **64***a* in the x direction). The light source optical axis **120***ax* is thus shifted from the system optical axis **100***ax* by a distance Dp equal to Wp/2 as shown in FIG. **2**.

As described above, each of the plurality of sub-beams output from the first lens array **140** is divided into two groups and is converted to practically a single kind of linearly polarized light having the same polarization direction by means of the polarized light generation optical system **160**. The plurality of sub-beams having the same polarization direction are superimposed on the lighting area LA by the superimposing lens **170** shown in FIG. **2**. Here the light illuminating the lighting area LA has a substantially homogeneous distribution of intensity.

The illumination optical system **100** (FIG. **1**) emits light having the same polarization direction (s-polarized light) and illuminates the liquid crystal light valves **300**R, **300**G, and **300**B via the color light separation optical system **200** and the relay optical system **220**.

The color light separation optical system **200** includes two dichroic mirrors **202** and **204**, and a reflection mirror **208**. This optical system functions to divide the light emitted from the illumination optical system **100** into three color lights of red, green, and blue. The first dichroic mirror **202** allows transmission of a red light component of the light emitted from the illumination optical system **100**, while reflecting a blue light component and a green light component. The red light R transmitted through the first dichroic mirror **202** is reflected by the reflection mirror **208** and goes toward the cross dichroic prism **520**. The red light R output from the color light separation optical system **200** reaches the liquid crystal light valve **300**R for red light through a field lens **232**. This filed lens **232** functions to convert the each sub-beam emitted from the illumination optical system **100** into a beam parallel to the center axis thereof. Field lenses **234** and **230** provided on the respective light incident sides of the other liquid crystal light valves **300**G and **300**B have similar functions.

The blue light B and the green light G are reflected by the first dichroic mirror **202**. The green light G is further reflected by the second dichroic mirror **204** and is output from the color light separation optical system **200** toward the cross dichroic prism **520**. The green light G output from the color light separation optical system **200** goes through the field lens **234** and reaches the liquid crystal light valve **300**G for green light. The blue light B transmitted through the second dichroic mirror **204** is, on the other hand, output from the color light separation optical system **200** and enters the relay optical system **220**.

The blue light B entering the relay optical system **220** passes through the relay optical system **220**, that is, an incident side lens **222**, a relay lens **226**, reflection mirrors **224** and **228**, and an exiting side lens (field lens) **230**, so as to reach the light crystal light valve **300**B for blue light. The relay optical system **220** is used for the blue light B, since the optical path length of the blue light B is greater than those of the other color lights R and G. The use of the relay optical system **220** enables the blue light B entering the incident side lens **222** to be transmitted as-is to the exiting side lens **230**.

The three liquid crystal light valves **300**R, **300**G, and **300**B respectively modulate the incident three color lights in response to given image information (image signals) and generate modulated lights. Each liquid crystal light valve includes a liquid crystal panel and polarizing plates provided at the incident light side and exiting light side thereof. The details of the liquid crystal light valve will be discussed later.

The cross dichroic prism **520** combines the three color lights modulated through the liquid crystal light valves **300**R, **300**G, and **300**B with one another to generate composite light representing a color image. The cross dichroic prism **520** has a red light reflection film **521** and a blue light reflection film **522** that are on interfaces of four rectangular prisms in a rough X shape. The red light reflection film **521** is composed of a dielectric multi-layered film that selectively reflects the red light. The blue light reflection film **522** is composed of a dielectric multi-layered film that selectively reflects the blue light. The combination of the red light reflection film **521** with the blue light reflection film **522** combines the three color lights together to generate composite light representing a color image.

The composite light generated by the cross dichroic prism **520** is output toward the projection lens **540**. The projection lens **540** projects the composite light emitted from the cross dichroic prism **520** so as to display a color image on the screen SC. A telecentric lens may be applied for the projection lens **540**.

FIG. **4** illustrates the main part of the projector **1000** shown in FIG. **1**. The optical system from the polarized light generation optical system **160** to the cross dichroic prism **520** shown in FIG. **1** is schematically illustrated in FIG. **4** by taking into account the polarization direction.

As discussed previously with FIG. **2**, the polarized light generation optical system **160** emits s-polarized light. The s-polarized light is separated into the red light R, the green light G, and the blue light B by means of the two dichroic mirrors **202** and **204** as described above. The polarization direction is not changed when the light passes through the dichroic mirrors **202** and **204**, so that the three color lights are all the s-polarized light.

The s-polarized red light R separated by the first dichroic mirror **202** is reflected by the reflection mirror **208** and enters the first liquid crystal light valve **300**R. The liquid crystal light valve **300**R includes a liquid crystal panel **301**R and two polarizing plates **302**Ri, **302**Ro arranged on the light incident side and the light exiting side of the liquid crystal panel **301**R. A λ/2 retardation plate **303**R is disposed on the light exiting side of the liquid crystal panel **301**R. The first polarizing plate **302**Ri is bonded to a first transmissive substrate **307**R, whereas the second polarizing plate **302**Ro and the λ/2 retardation plate **303**R are bonded to a second transmissive substrate **308**R. The polarization axes of the first and second polarizing plates **302**Ri, **302**Ro are arranged to be perpendicular to each other. The first polarizing plate **302**Ri is an s-polarized light transmission polarizing plate that allows transmission of the s-polarized light. The second polarizing plate **302**Ro is a p-polarized light transmission polarizing plate that allows transmission of the p-polarized light.

The s-polarized red light R entering the first liquid crystal light valve **300**R is mostly transmitted through the transmissive substrate **307**R and the s-polarized light transmission polarizing plate **302**Ri, and enters the liquid crystal panel **301**R. The liquid crystal panel **301**R converts part of the incident s-polarized lights into p-polarized lights, and the p-polarized light transmission polarizing plate **302**Ro arranged on the light exiting side emits only the p-polarized lights. The p-polarized light emitted from the p-polarized light transmission polarizing plate **302**Ro enters the λ/2 retardation plate **303**R via the transmissive substrate **308**R and is converted to s-polarized light by the λ/2 retardation plate **303**R.

The s-polarized green light G separated by the second dichroic mirror **204** enters the second liquid crystal light valve **300**G. The second liquid crystal light valve **300**G includes a liquid crystal panel **301**G, an s-polarized light transmission polarizing plate **302**Gi arranged on the light incident side of the liquid crystal panel **301**G, and a p-polarized light transmission polarizing plate **302**Go arranged on the light exiting side. The first and second polarizing plates **302**Gi, **302**Go are respectively bonded to transmissive substrates **307**G, **308**G. The s-polarized green light G entering the second liquid crystal light valve **300**G is mostly transmitted through the transmissive substrate **307**G and the s-polarized light transmission polarizing plate **302**Gi, and enters the liquid crystal panel **301**G. The liquid crystal panel **301**G converts part of the incident s-polarized lights into p-polarized lights, and the p-polarized light transmission polarizing plate **302**Go arranged on the light exiting side emits only the p-polarized lights. The p-polarized light emitted from the p-polarized light transmission polarizing plate **302**Go mostly passes through the transmissive substrate **308**G.

The s-polarized blue light B separated by the second dichroic mirror **204** is reflected by the two reflection mirrors **224**, **228** and enters the third liquid crystal line valve **300**B. The third liquid crystal light valve **300**B includes a liquid crystal panel **301**B, two polarizing plates **302**Bi and **302**Bo, a λ/2 retardation plate **303**B, a first transmissive substrate **307**B to which the first polarizing plate **303**Bi is bonded, and a second transmissive substrate **308**B to which the second polarizing plate **302**Bo and the λ/2 retardation plate **303**B are bonded. The structure of the third liquid crystal light valve **300**B is identical with the structure of the first liquid crystal light valve **300**R.

In the structure of this embodiment, the s-polarized light transmission polarizing plates **302**Ri, **302**Gi, **302**Bi are all arranged on the respective light incident sides of the three liquid crystal light valves **300**R, **300**G, **300**B, whereas the p-polarized light transmission polarizing plates **302**Ro, **302**Go, **302**Bo are all arranged on their light exiting faces. The respective liquid crystal panels **301**R, **301**G, **301**B have a same orientation of liquid crystal.

In this embodiment, the respective liquid crystal light valves are constructed in such a manner that the lights emitted from the first and third liquid crystal light valves **300**R and **300**B are s-polarized lights and the light emitted from the second liquid crystal light valve **300**G is p-polarized light. This arrangement enhances the light utilization efficiency of the cross dichroic prism **520**. The two reflection films **521**, **522** formed in the cross dichroic prism **520** have the better reflection characteristic for the s-polarized light than that for the p-polarized light, and have the better transmission characteristic for the p-polarized light than that for the s-polarized light. The light to be reflected by the two reflection films **521**, **522** is thus s-polarized light, while the light to be transmitted through the two reflection films **521**, **522** is p-polarized light.

The first through the third liquid crystal panels **301**R, **301**G, **301**B of this embodiment correspond to the first through the third electro-optical devices of the present invention.

B. Optical Component (a)

The transmissive substrates **307**R, **307**G, **307**B, **308**R, **308**G, and **308**B shown in FIG. **4** are rock crystal substrates composed of rock crystal. Here the rock crystal represents single crystal of SiO_2. The rock crystal may be artificial or natural.

Mass of the artificial rock crystal can be manufactured at once with a growth furnace known as an autoclave. The rock crystal has a lower hardness than that of sapphire, which is conventionally used for the transmissive substrate that holds the polarizing plate, and is readily processed to a predetermined shape. The rock crystal substrate is thus relatively easily manufactured.

FIG. **5** illustrates the crystal structure of rock crystal. The rock crystal is a crystal of trigonal system and is defined by crystal planes, that is, planes R, r, and m. X, Y, and Z axes of the rock crystal are specified as illustrated.

FIGS. **6**(A) and **6**(B) illustrate the rock crystal substrate used in this embodiment. FIG. **6**(A) shows a rock crystal substrate RC**1** having the Z axis of rock crystal arranged to be substantially parallel to the surface of the substrate, that is, to be included in the plane of the substrate. The rock crystal substrate RC**1** is obtained by successively polishing the rock crystal shown in FIG. **5**. For example, the rock crystal substrate RC**1** is obtained by polishing the rock crystal in such a manner that a face parallel to the YZ plane defined by the Y axis and the Z axis shown in FIG. **5** forms the surface of the substrate.

FIG. **6**(B) shows a rock crystal substrate RC**2** having the Z axis of rock crystal arranged to be substantially perpendicular to the surface of the substrate. The rock crystal substrate RC**2** is obtained by polishing the rock crystal in such a manner that a face parallel to the XY plane defined by the X axis and the Y axis shown in FIG. **5** forms the surface of the substrate.

Either of the rock crystal substrates shown in FIGS. **6**(A) and **6**(B) is applied for the transmissive substrates **307**R, **307**G, **307**B, **308**R, **308**G, and **308**B of this embodiment. The polarizing plate is bonded to the rock crystal substrate to maintain a predetermined relation.

FIGS. **7**(A) through **7**(C) illustrate an optical component **360** provided on the light exiting side of the second liquid crystal light valve **300**G (FIG. **4**). The optical component **360** includes the rock crystal substrate **308**G and the polarizing plate **302**Go mounted on the rock crystal substrate **308**G. FIGS. **7**(A) through **7**(C) show diverse relations between the rock crystal substrate **308**G and the polarizing plate **302**Go.

FIG. **7**(A) uses the rock crystal substrate **308**G having the Z axis of rock crystal that is arranged to be substantially parallel to the surface of the substrate as shown in FIG. **6**(A). The polarizing plate **302**Go is bonded to the rock crystal substrate **308**G, such that a polarization axis pa of the polarizing plate **302**Go is substantially parallel to the Z axis of the rock crystal substrate. More concretely, the polarizing plate **302**Go is attached to the rock crystal substrate **308**G, such that the inclined angle of the polarization axis pa relative to the Z axis of rock crystal is within about 3 degrees. As discussed later, the smaller inclined angle is desirable, and the preferable setting is, for example, within about 1 degree.

FIG. **7**(B) also uses the rock crystal substrate **308**G having the Z axis of rock crystal that is arranged to be substantially parallel to the surface of the substrate as shown in FIG. **6**(A). In the example of FIG. **7**(B), however, the polarizing plate **302**Go is bonded to the rock crystal substrate **308**G such that the polarization axis pa is substantially parallel to the Z axis of rock crystal. More concretely, the polarization plate **302**Go is attached to the rock crystal substrate **308**G, such that the inclined angle of the polarization axis pa relative to the Z⊥ direction substantially perpendicular to the Z axis is within about 3 degrees. In this example, the smaller inclined angle is desirable, and the preferable setting is, for example, within about 1 degree.

In FIGS. **7**(A) and **7**(B), the inclined angle is regulated to make the polarization axis pa of the polarizing plate **302**Go substantially parallel to or substantially perpendicular to the Z axis of rock crystal, since the rock crystal is an optically uniaxial crystal. In rock crystal, the Z axis is an optic axis, and the refractive index in the Z-axis direction is different from the refractive index in the direction perpendicular to the Z axis. When light enters rock crystal, birefringence may change the polarizing state of light. As shown in FIGS. **7**(A) and **7**(B), when the travelling direction of the linearly polarized (p-polarized) green light G passing through the p-polarized light transmission polarizing plate **302**Go is substantially perpendicular to the optic axis (Z axis) and the electric vector of the linearly polarized light is substantially parallel to or substantially perpendicular to the optic axis (Z axis), the linearly polarized light is emitted with little variation in polarizing state.

FIG. **7**(C) uses the rock crystal substrate **308**G having the Z axis of rock crystal that is arranged to be substantially perpendicular to the surface of the substrate as shown in FIG. **6**(B). Here the polarization axis pa of the polarizing plate **302**Go is kept substantially perpendicular to the Z axis of the rock crystal substrate **308**G. The p-polarized green light G output from the polarizing plate **302**Go travels practically in parallel to the optic axis (Z axis) of rock crystal. This leads to little variation in polarizing state of the light passing through the rock crystal substrate **308**G. However, when the p-polarized green light G passing through the rock crystal substrate **308**G is not sufficiently parallel to the Z axis of rock crystal, the polarizing state of light varies. It is accordingly preferable that the incident light entering the rock crystal substrate **308**G is parallel to the Z axis of rock crystal.

In the case where the polarizing plate **302**Go is arranged to face the liquid crystal panel **301**G as shown in FIG. **4**, even a variation in polarizing state of the rock crystal substrate **308**G does not lower the contrast of the image light. In the arrangement of FIG. **7**(C), it is not required to bond the polarizing plate **302**Go to the rock crystal substrate **308**G with high accuracy. This advantageously facilitates the process of bonding the polarizing plate **302**Go to the rock crystal substrate **308**G.

In the case of application of the rock crystal substrate **308**G having the Z axis of rock crystal substantially parallel to the surface of the substrate as shown in FIGS. **7**(A) and **7**(B), the desirable arrangement is to make the light output from the polarizing plate **302**Go enter the rock crystal substrate **308**G as shown in FIG. **4**. If the arrangement allows the light to enter the rock crystal substrate **308**G and the polarizing plate **302**Go in this sequence, the modulated light of the changed polarizing state through the rock crystal substrate **308**G enters the polarizing plate **302**Go. The polarizing plate **302**Go cuts off part of the light to be transmitted and thereby lowers the contrast of the image light (modulated light) emitted from the liquid crystal light valve **300**G. On the other hand, the arrangement as shown in FIG. **4** advantageously prevents a decrease in contrast of the image light emitted from the liquid crystal light valve **300**G, even when the polarizing state of the linearly polarized light (p-polarized light) through the rock crystal substrate **308**G changes a little.

By the way, the polarizing plate **302**Go cuts off the light components other than a preset polarized light component (p-polarized light) in the incident modulated light emitted from the liquid crystal panel **301**G, and accordingly generates heat. The generated heat deteriorates the polarizing plate. It is accordingly preferable to minimize the temperature rise of the polarizing plate.

The thermal conductivity of rock crystal in the direction parallel to the Z-axis is different from that in the direction perpendicular to the Z axis. The thermal conductivity of rock crystal is about 9.3 (W/(m·k)) in the direction parallel to the Z axis and about 5.4 (W/(m·k)) in the direction perpendicular to the Z axis. Namely the rock crystal has the higher thermal conductivity in the direction parallel to the Z axis.

Compared with the rock crystal substrate **308**G having the Z axis of rock crystal that is arranged to be substantially perpendicular to the surface of the substrate as shown in FIG. **7**(C), the rock crystal substrate **308**G having the Z axis of rock crystal that is arranged to be substantially parallel to the surface of the substrate as shown in FIGS. **7**(A) and **7**(B) more effectively suppresses the temperature rise of the polarizing plate **302**Go and homogenizes the in-plane temperature distribution of the polarizing plate **302**Go.

It should be noted that the thermal conductivity of sapphire is higher than that of rock crystal. However, a relatively thicker rock crystal substrate exerts the equivalent heat dissipation effects to those of the sapphire substrate. For example, the heat dissipation effects of the sapphire substrate having the thickness of about 0.7 mm are equivalent to those of the rock crystal substrate having the thickness of about 1.5 mm.

FIGS. **7**(A) through **7**(C) regard the relation between the rock crystal substrate **308**G and the polarizing plate **302**Go disposed on the light exiting side of the second liquid crystal light valve **300**G shown in FIG. **4**. The similar relation is maintained between the rock crystal substrate **307**G and the polarizing plate **302**Gi disposed on the light incident side. In the latter case, the rock crystal substrate **307**G is preferably arranged to make the Z axis of rock crystal substantially parallel to or perpendicular to the electric vector of the incident linearly polarized light (s-polarized light) and substantially parallel to the surface of the substrate. The rock crystal substrate **307**G thus enables output of the s-polarized light with little variation in polarizing state of the incident s-polarized light. When the rock crystal substrate **307**G is arranged to make the Z axis of rock crystal substantially perpendicular to the surface of the substrate, the rock crystal substrate **307**G enables output of the s-polarized light with little variation in polarizing state of the incident s-polarized light that is substantially parallel to the Z axis of rock crystal.

It is further desirable that the rock crystal substrate **307**G and the polarizing plate **302**Gi are arranged to make the light output from the rock crystal substrate **307**G enter the polarizing plate **302**Gi as shown in FIG. **4**. If the arrangement allows the light to enter the polarizing plate **302**Gi and the rock crystal substrate **307**G in this sequence, insufficient accuracy of the adjusted relation between the Z axis of the rock crystal substrate **307**G and the polarization axis pa of the polarizing plate **302**Gi causes the polarizing state of the linearly polarized light emitted from the polarizing plate **302**Gi to be changed during passing through the rock crystal substrate **307**G. The light other than the linearly polarized light may accordingly enter the liquid crystal panel **301**G. In the arrangement that the Z axis of the rock crystal substrate **307**G is substantially perpendicular to the surface of the substrate, and the incident light that is not sufficiently parallel to the Z axis of rock crystal also causes a variation in polarizing state. Such incident light into the liquid crystal panel **301**G undesirably lowers the contrast of the image light emitted from the liquid crystal light valve **300**G. Even when the rock crystal substrate **307**G changes the polarizing state of the linearly polarized light (s-polarized light), however, the arrangement shown in FIG. **4** causes the light to pass through the polarizing plate **302**Gi after the rock crystal substrate **307**G. Only the linearly polarized light (s-polarized light) accordingly enters the liquid crystal panel **301**G. This advantageously prevents a decrease in contrast of the image light emitted from the liquid crystal light valve **300**G.

The above description regards the relation between the rock crystal substrate and the polarizing plate provided on the light incident side and the light exiting side of the second liquid crystal light valve **300**G (FIG. **4**). The similar relation should be maintained with regard to the other liquid crystal light valves **300**R and **300**B.

In should be noted that, in the second liquid crystal light valve **300**G, only the polarizing plate **302**Go is bonded to the rock crystal substrate **308**G provided on the light exiting side. On the other hand, in the first and the third liquid crystal light valves **300**R and **300**B, the λ/2 retardation plates **303**R, **303**B as well as the polarizing plates **302**Ro, **302**Bo are attached to the rock crystal substrates **308**R, **308**B provided on the light exiting side. The λ/2 retardation plates **303**R, **303**B also generate heat during the light passing through them. Like the polarizing plates, the rock crystal substrates **308**R, **308**B function to suppress the temperature rise.

Each of the optical components provided on the light incident side and the light exiting side of the liquid crystal light valve, such as the optical component **360** shown in FIGS. **7**(A) through **7**(C), includes a rock crystal substrate as the rock crystal member; and optical elements like the polarizing plate and the λ/2 retardation plate mounted on the rock crystal substrate. The optical components composed of rock crystal are readily manufactured. This facilitates manufacture of the projector **1000**. Rock crystal has a relatively high thermal conductivity and thus effectively suppresses the temperature rise of the optical component.

C. Optical Component (b)

FIG. **8** schematically illustrates the optical component (liquid crystal panel) **301**G included in the second liquid crystal light valve **300**G (FIG. **4**). As illustrated, the liquid crystal panel **301**G includes a pair of transmissive substrates **321** and **322**; and a liquid crystal layer **330** interposed between the pair of transmissive substrates **321** and **322**. A transparent common electrode **321***a* is formed on one face of the first transmissive substrate **321** facing the liquid crystal layer **330**. Thin-film transistors (not shown) and transparent pixel electrodes **322***a* are formed in a matrix corresponding to the respective pixels on one face of the second transmissive substrate **322** facing the liquid crystal layer **330**. The liquid crystal panel **301**G is an active matrix-type. The liquid crystal panels **301**R and **301**B included in the other liquid crystal light valves **300**R and **300**B have same structure.

In FIG. **8**, the pair of transmissive substrates **321** and **322** are rock crystal substrates. In the first rock crystal substrate **321**, the Z axis of rock crystal is substantially parallel to both the surface of the substrate and the y axis. The s-polarized green light G entering the first rock crystal substrate **321** thus enters the liquid crystal layer **330** with little variation in polarizing state. The polarizing state of the s-polarized light entering and passing through the liquid crystal layer **330** changes with regard to each pixel. The modulated light is accordingly output from the liquid crystal layer **330**. In the first rock crystal substrate **321**, the Z axis of rock crystal may be arranged to be substantially parallel to the x axis. In the second rock crystal substrate **322**, the Z axis of rock crystal is substantially parallel to both the surface of the substrate and the x axis. The modulated light entering the second rock crystal substrate **322** is accordingly output from the second rock crystal substrate **322** with little variation in polarizing state. In the second rock crystal substrate **322**, the Z axis of rock crystal may be arranged to be substantially parallel to the y axis.

Each Z axis of the first and second rock crystal substrates **321**, **322** is substantially parallel to the surface of the substrate in FIG. **8**, but may be arranged to be substantially perpendicular to the surface of the substrate. The polarizing state of light hardly changes when the light passing through the rock crystal substrate **321** or **322** is substantially parallel to the Z axis of rock crystal. When the light passing through the rock crystal substrate **321** or **322** is not sufficiently parallel to the Z axis of rock crystal, however, the polarizing state of the polarized light changes. It is thus required to optimize the orientation and the type of liquid crystal corresponding to the degree of the change. The arrangement of making the Z axis of rock crystal substantially parallel to the surface of the substrate is more effective to suppress the temperature rise of the liquid crystal panel **301**G. Namely the preferable arrangement is to make the Z axis of rock crystal substantially parallel to the surface of the substrate as shown in FIG. **8**.

Application of the rock crystal substrates **321**, **322** as the transmissive substrates forming the light incident face and the light exiting face of the optical component (liquid crystal panel) **301**G facilitates manufacture of the optical component **301**G, while effectively suppressing the temperature rise of the optical component **301**G.

D. Optical Component (c)

FIG. **9** is an enlarged view illustrating the optical component (cross dichroic prism) **520** provided as the color light composition optical system (FIG. **4**). As discussed previously, the cross dichroic prism **520** includes four rectangular prisms (columnar rock crystal members) **511–514** that are divided by interfaces formed in a rough X shape. The red light reflection film **521** and the blue light reflection film **522** that selectively reflect lights having wavelengths in respective preset ranges are formed on the interfaces in the rough X shape.

In this optical component **520**, the four rectangular prisms **511–514** are made of rock crystal. In FIG. **9**, the Z axes of the four rectangular prisms **511–514** are substantially parallel to the y direction. Namely the rectangular prisms **511–514** are arranged in such a manner that each Z axis of rock crystal is kept to be substantially perpendicular to the center axis of the light passing through each rectangular prism. In FIG. **9**, the lights passing through the four rectangular prisms **511–514** are linearly polarized light (s-polarized light or p-polarized light), and the rectangular prisms **511–514** are disposed such that each Z axis of rock crystal is kept to be substantially parallel to or substantially perpendicular to the electric vector of the linearly polarized light.

More concretely, the electric vector of the red light R (s-polarized light) entering the first rectangular prism **511** is substantially parallel to the Z axes of rock crystal of the two rectangular prisms **511, 514** before and after the reflection by the red light reflection film **521**. Similar arrangement is observed for the blue light B (s-polarized light) entering the third rectangular prism **513**. On the other hand, the electric vector of the green light G (p-polarized light) entering the second rectangular prism **512** is substantially perpendicular to the z axes of rock crystal of the four rectangular prisms **511–514** before and after the transmission through the two reflection films **521** and **522**. The linearly polarized light entering the first through the third rectangular prisms **511–513** are output from the fourth rectangular prism **514** with little variation in polarizing state.

The Z axes of rock crystal of the four rectangular prisms **511–514** are substantially parallel to the y direction in FIG. **9**, but may be arranged to be substantially parallel to the z direction.

In the optical component (cross dichroic prism) **520** shown in FIG. **9**, the four rectangular prisms **511–514** are made of rock crystal. Application of rock crystal facilitates manufacture of the optical component **520**, while effectively suppressing the temperature rise of the optical component **520**.

By the way, in FIG. **4**, the λ/2 retardation plate **303**R of the first liquid crystal light valve **300**R is attached to the rock crystal substrate **308**R, but may alternatively be attached to the light incident face of the first rectangular prism **511**. In the latter case, the rectangular prism **511** functions to suppress the temperature rise of the λ/2 retardation plate **303**R. The λ/2 retardation plate **303**B of the third liquid crystal light valve **300**B has the similar function. In FIG. **4**, the polarizing plate **302**Go of the second liquid crystal light valve **300**G is attached to the rock crystal substrate **308**G, but may alternatively be attached to the light incident face of the second rectangular prism **512**. In the latter case, the rectangular prism **512** functions to suppress the temperature rise of the polarizing plate **302**Go and allows omission of the rock crystal substrate **308**G.

Although the cross dichroic prism **520** is used as the optical component of the color light composition optical system in this embodiment, another dichroic prism may be applied for the optical component.

FIG. **10** illustrates another dichroic prism **550**. This dichroic prism **550** includes two optical components (color selection prisms) **560** and **570**.

The first color selection prism **560** has two rectangular prisms **561** and **562**, and a red light reflection film **551** that selectively reflects the red light R is formed on the interface between the two rectangular prisms **561** and **562**. Each of the rectangular prisms **561** and **562** is made of rock crystal, and the Z axis of rock crystal is set in the y direction. The second color selection prism **570** has a similar structure, and a blue light reflection film **552** that selectively reflects the blue light B is formed on the interface between two rectangular prisms **571** and **572**.

Like the cross dichroic prism **520** of FIG. **9**, the linearly polarized light entering the two rectangular prisms **561, 562** of the first color selection prism **560** and the second rectangular prism **572** of the second color selection prism **570** is output from the second rectangular prism **572** of the second color selection prism **570** with little variation in polarizing state.

By the way, the cross dichroic prism **520** of FIG. **9** and the dichroic prism **550** of FIG. **10** are used as the color light composition optical system for combining the three color

lights. They may alternatively be used as the color light separation optical system when the traveling direction of light is reversed. If white light enters the light exiting face of the cross dichroic prism **520** or the dichroic prism **550** and the respective color lights output from its light incident face, the cross dichroic prism **520** or the dichroic prism **550** is applicable for the color light separation optical system. Namely either of these prisms **520** and **550** may be used for the color light separation optical system **200** shown in FIG. **1**.

E. Optical Component (d)

FIG. **11** is an enlarged view illustrating the optical component (polarization beam splitter array) **64** included in the illumination optical system **100** (FIG. **2**). FIG. **11** is an enlarged view of FIG. **3**(B). The shading plate **62** and the selective retardation plate **66** are illustrated apart to clarify the relation to FIG. **3**(B).

As discussed previously with FIGS. **3**(A) and **3**(B), the polarization beam splitter array **64** is constructed by joining the plurality of columnar transmissive members **64*c*** having the practically parallelogrammatic cross section. The polarization separation films **64*a*** and the reflection films **64*b*** are alternately formed on the interfaces of the respective adjoining transmissive members **64*c***.

The respective transmissive members **64*c*** are rock crystal members made of rock crystal. In FIG. **11**, the Z axis of rock crystal of each rock crystal member **64*c*** is substantially parallel to the y direction. Namely each rock crystal member **64*c*** is arranged in such a manner that the Z axis of rock crystal is kept to be substantially perpendicular to the center axis of the light passing through the rock crystal member **64*c***.

In the polarization beam splitter array **64**, as shown in FIG. **11**, the linearly polarized light (s-polarized light or p-polarized light) separated by the polarization separation film **64*a*** goes through the rock crystal member **64*c***. In FIG. **11**, the rock crystal member **64*c*** is arranged such that the Z axis of rock crystal is kept to be substantially parallel to or substantially perpendicular to the electric vector of the linearly polarized light. Under such conditions, the s-polarized light and the p-polarized light separated by the polarization separation film **64*a*** are output from the polarization beam splitter array **64** with little variation in polarizing state.

The optical component (polarization beam splitter array) **64** shown in FIG. **11** includes the transmissive members **64*c*** made of rock crystal. Application of rock crystal facilitates manufacture of the optical component **64**, while effectively suppressing the temperature rise of the optical component **64**. Attachment of the shading plate **62** and the selective retardation plate **66** to the polarization beam splitter array **64** more effectively suppresses the temperature rise of the shading plate **62** and the selective retardation plate **66**, and homogenizes the temperature distribution.

It should be noted that the Z axis of rock crystal of each rock crystal member **64*c*** is substantially parallel to the y direction in FIG. **11**, but may be arranged to be substantially parallel to the x direction or the z direction. In the structure that the shading plate **62** and the selective retardation plate **66** are bonded to the polarization beam splitter array **64**, the arrangement of making the Z axis of rock crystal of each rock crystal member **64*c*** substantially parallel to the y direction more effectively suppresses the temperature rise of the shading plate **62** and the selective retardation plate **66** and homogenizes the temperature distribution. In the case of the above modified direction of the Z axis of rock crystal, when the s-polarized light and the p-polarized light separated by the polarization separation film **64***a* travel in substantially parallel to the x direction or to the z direction, the s-polarized light and the p-polarized light are output from the polarization beam splitter array **64** with little variation in polarizing state.

The polarization beam splitter array **64** of FIG. **11** mounted on the projector **1000** of FIG. **11** may be replaced by a polarization beam splitter.

FIG. **12** illustrates a polarization beam splitter. This optical component (polarization beam splitter) **600** includes two transmissive members **610** and **620** of practically triangular prism. A polarization separation film **600***a* that divides incident non-polarized light (s+p) into s-polarized light and p-polarized light is formed on the interface of the two transmissive members **610** and **620**. In the application of this polarization beam splitter **600** to the projector **1000**, as shown in FIG. **12**, a λ/2 retardation plate **630** is located on the light exiting face of the first transmissive member **610** to convert the p-polarized light output from the first transmissive member **610** into s-polarized light. A reflection mirror (not shown) is disposed on the light exiting side of the second transmissive member **620**, so that the light emitted from the polarization beam splitter **600** travels in the z direction. It should be noted that the polarization beam splitter **600** corresponds to part of the polarization beam splitter array **64** shown in FIG. **11**. Namely one block of the polarization beam splitter array **64** including the polarization separation film **64***a* corresponds to the polarization beam splitter **600**.

In FIG. **12**, the two transmissive members **610** and **620** are rock crystal members made of rock crystal. The Z axis of rock crystal of each rock crystal member **610** or **620** is substantially parallel to the y direction. The s-polarized light and the p-polarized light separated by the polarization separation film **600***a* are thus output from the polarization beam splitter **600** with little variation in polarizing state.

Such application facilitates manufacture of the polarization beam splitter **600** and effectively suppresses the temperature rise of the polarization beam splitter **600**.

Each Z axis of rock crystal of the first and the second rock crystal members **610** and **620** is substantially parallel to the y direction in FIG. **12**, but may be arranged to be substantially parallel to the x direction or the z direction. In the structure that the λ/2 retardation plate **630** is bonded to the polarization beam splitter **600**, the arrangement of making the Z axis of rock crystal of each rock crystal member **610**, **620** substantially parallel to the y direction more effectively suppresses the temperature rise of the λ/2 retardation plate **630**, and homogenizes the temperature distribution. In the case of the above modified direction of the Z axis of rock crystal, when the s-polarized light and the p-polarized light separated by the polarization separation film **600***a* travel in substantially parallel to the x direction or to the z direction, the s-polarized light and the p-polarized light are output from the polarization beam splitter **600** with little variation in polarizing state.

F. Optical Component (e)

FIG. **13** illustrates the optical component (superimposing lens) **170** included in the illumination optical system **100** (FIG. **2**). The superimposing lens **170** is made of rock crystal. The Z axis of rock crystal of the superimposing lens **170** is substantially parallel to the y direction in FIG. **13**. The superimposing lens **170** is thus arranged, such that the Z axis of rock crystal is substantially perpendicular to the center axis of the light entering the superimposing lens **170** and is substantially parallel to the electric vector of the linearly polarized light (s-polarized light). The light traveling in the Z direction of rock crystal is thus output with little variation in polarizing state.

Such application more effectively suppresses the temperature rise of the superimposing lens **170** and homogenizes the in-plane temperature distribution of the superimposing lens **170**.

It should be noted that the Z axis of rock crystal of the superimposing lens **170** is substantially parallel to the y direction in FIG. **13**, but may be arranged to be substantially parallel to the x direction.

In FIG. **13**, the present invention is applied for the superimposing lens **170** included in the illumination optical system **100** (FIG. **2**), but may be applied for other lenses in the illumination optical system **100**, for example the first and the second lens arrays **140**, **150**, as well as the field lenses **230**, **232**, **234** and the projection lens **540** shown in FIG. **1**.

The Z axis of rock crystal of the superimposing lens **170** may alternatively be arranged to be substantially parallel to the z direction in the illustration of FIG. **13**. The polarizing state of light hardly changes when the center axis of the light passing through the superimposing lens **170** is substantially parallel to the Z axis of rock crystal. Insufficient parallelism to the Z axis of rock crystal changes the polarizing state of light. It is accordingly preferable to locate the lens at a position that hardly utilizes specified polarized light such as the linearly polarized light or at a position that is hardly affected by the variation in polarizing state.

As discussed above, the diverse optical components including the rock crystal members made of rock crystal (see FIGS. **7** through **13**) are disposed on the optical path including the illumination optical system **100** and the projection lens **540**. Such arrangement facilitates manufacture of the optical components and thereby manufacture of the projector **1000**.

The present invention is not restricted to the above embodiment or its modifications, but there may be many other modifications, changes, and alterations without departing from the scope or spirit of the main characteristics of the present invention. Some examples of possible modification are given below.

(1) In the above embodiment, as shown in FIG. **4**, the polarizing plates **302**Ri, **302**Gi, **302**Bi on the light incident sides of the first through the third liquid crystal light valves **300**R, **300**G, **300**B are attached to the independently provided rock crystal substrates **307**R, **307**G, **307**B. They may alternatively be attached to the rock crystal substrates **321** (FIG. **8**) forming the light incident faces of the liquid crystal panels **301**R, **301**G, **301**B. Such modification allows omission of the rock crystal substrates **307**R, **307**G, **307**B on the light incident sides of the respective liquid crystal light valves. However, the attachment of the polarizing plates **302**Ri, **302**Gi, **302**Bi to the independent rock crystal substrates **307**R, **307**G, **307**B as shown in FIG. **4** advantageously ensures the greater effect on suppression of the temperature rise of the polarizing plates. It should be noted that the similar omission is allowed for the polarizing plates on the light exiting sides. In general, the optical component including an optical element mounted on the rock crystal substrate may be provided on at least one of the light incident side and the light exiting side of the liquid crystal light valve.

(2) In any of the optical components shown in FIGS. **7** through **13** of the above embodiment, the rock crystal member is arranged in such a manner that the Z axis of rock crystal is substantially perpendicular to or substantially parallel to the center axis of the light passing through the rock crystal member. However, when it is not required to

take into account the effect of the variation in polarizing state, the Z axis of rock crystal may be oriented in another direction. The rock crystal member of such orientation also facilitates manufacture of the optical component and thereby manufacture of the projector, while effectively suppressing the temperature rise of the optical component. The only requirement is that the optical component including the rock crystal member made of rock crystal is provided on the optical path including the illumination optical system and the projection optical system.

(3) The above embodiment regards application of the present invention to the transmissive-type projector. The principle of the present invention is also applicable to a reflective-type projector. In the 'transmissive-type' projector, the electro-optical device working as the light modulation means allows transmission of light; for example, a transmissive-type liquid crystal panel. In the 'reflective-type' projector, on the other hand, the electro-optical device working as the light modulation means reflects light; for example, a reflective-type liquid crystal panel. Application of the present invention to the reflective-type projector ensures the similar advantages to those attained by application to the transmissive-type projector.

(4) In the above embodiment, the projector **1000** uses the liquid crystal panels as the electro-optical devices, but may instead use micromirror-type light modulation devices. A typical example of the micromirror-type light modulation device is DMD (digital micromirror device) (trade mark by TI Corporation). In general, any electro-optical device that modulates incident light in response to image information is applicable.

(5) The above embodiment regards the projector **1000** that displays color images. The present invention is also applicable to the projector that displays monochromatic images.

Industrial Applicability

The present invention is applicable to a diversity of projectors that project and display images.

What is claimed is:

1. A projector comprising:

an illumination optical system for emitting a light;

an electro-optical device for modulating the light emitted from the illumination optical system in response to image information; and

a projection optical system for projecting a modulated light generated by the electro-optical device,

wherein the illumination optical system comprises a polarized light generation section for emitting a predetermined polarized light,

the polarized light generation section comprising:

an optical component for dividing an incident light into two different polarized lights; and

a selective retardation plate for adjusting one of the two polarized lights output from the optical component to the other,

the optical component comprising:

a plurality of rock crystal members composed of rock crystal and arrayed in a predetermined direction; and

a polarization separation film and a reflection film that are alternately arranged on interfaces of the plurality of rock crystal members.

2. The projector in accordance with claim **1**,

wherein each of the plurality of rock crystal members is disposed in such a manner that a Z axis of the rock crystal is substantially perpendicular to a center axis of a light passing through the each rock crystal member and the Z axis of the rock crystal is set to be substantially parallel to a surface of the each rock crystal member.

3. A projector comprising:

an illumination optical system for emitting a light;

an electro-optical device for modulating the light emitted from the illumination optical system in response to image information; and

a projection optical system for projecting a modulated light generated by the electro-optical device,

wherein the illumination optical system comprises a polarized light generation section for emitting a predetermined polarized light,

the polarized light generation section comprising:

an optical component for dividing an incident light into two different polarized lights; and

a selective retardation plate for adjusting one of the two polarized lights output from the optical component to the other,

the optical component comprising:

a rock crystal member composed of rock crystal; and

a polarization separation film formed on the rock crystal member.

4. The projector in accordance with claim **3**,

wherein the rock crystal member is disposed in such a manner that a Z axis of the rock crystal is substantially perpendicular to a center axis of a light passing through the rock crystal member and the Z axis of the rock crystal is set to be substantially parallel to a surface of the rock crystal member.

5. The projector in accordance with claim **3**,

wherein the rock crystal member is disposed in such a manner that a Z axis of the rock crystal is substantially parallel to a center axis of a light passing through the rock crystal member and the Z axis of the rock crystal is set to be substantially perpendicular to a surface of the rock crystal member.

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